

**Materials  
Systems  
Inc.**

## **Piezocomposites for Active Surface Control**

Final Technical Report

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## Executive Summary

This program ("Piezocomposites for Active Surface Control," Contract No. N00014-95-C-0005) was carried out by Materials Systems Inc. (MSI), Littleton, MA, from December 1994 to June 1997. Dr. Richard Gentilman and Mr. Daniel Fiore were Program Manager and Lead Engineer, respectively. The Naval Research Laboratory (NRL) participated in this program as a separately-funded team member. The NRL effort was carried out at the Physical Acoustics branch in Washington, DC and the Underwater Sound Reference Detachment (USRD) in Orlando, FL. During the period of the program, USRD became part of the Naval Undersea Warfare Center (NUWC). The Physical Acoustics branch (Drs. Robert Corsaro and Brian Houston) supported the program with SmartPanel component design and evaluation, while all SonoPanel acoustic and environmental testing was performed by USRD (Drs. Robert Ting and Thomas Howarth).

The program consisted of two technical tracks: Track 1 addressed the development, optimization, scale-up, and testing of 1-3 piezocomposite SonoPanel transducers. Track 2 addressed the development of SmartPanels (which contain net shape molded accelerometers and 1-3 pressure sensors co-located with a 1-3 actuator layer) for active surface control.

Track 1 included several tasks. An injection molding process for PZT-4 ceramic was established, and tooling for molding 25% PZT ceramic preforms was designed, fabricated, and put into service (Figure 1). Both soft matrix and stiff matrix SonoPanels were fabricated and tested acoustically and environmentally. As a result of successful environmental testing, which included temperature (4° and 22°C), hydrostatic pressure (to 6900 kPa), and multiple explosive shock, both SonoPanel types were deemed qualified for US Navy systems.

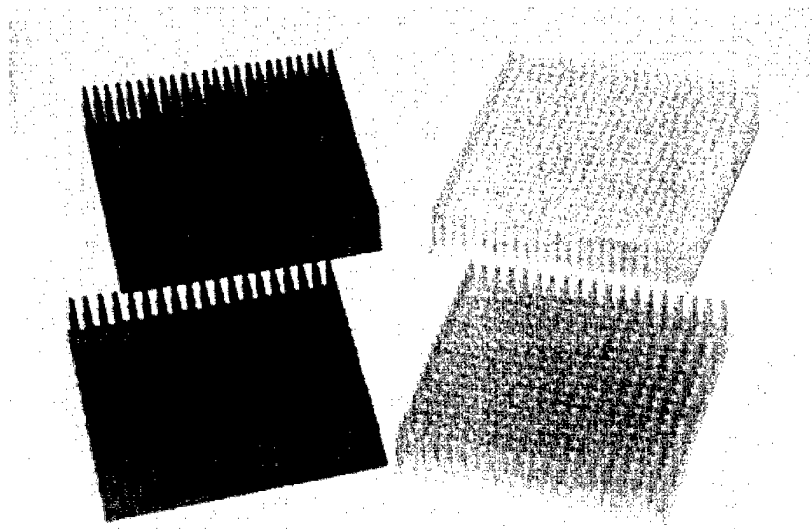


Figure 1. Injection Molded Preforms (clockwise from top left: 25 vol.% PZT-4, 25 vol.% PZT-5H, 15 vol.% PZT-5H, 15 vol.% PZT-4).

In addition, both SonoPanel types were scaled-up to 750 x 750 mm (Figure 2) and tested, with acoustic performance meeting all expectations.

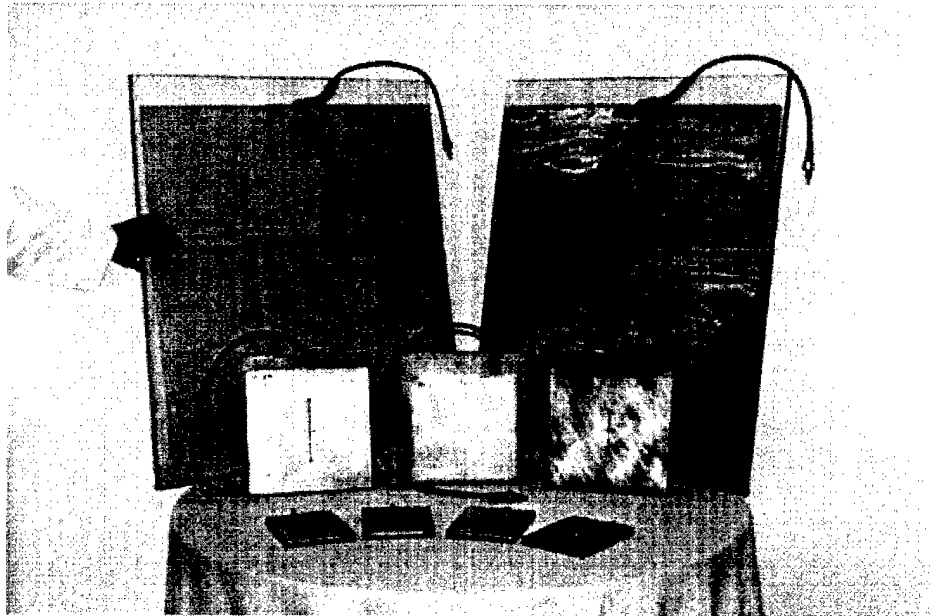


Figure 2. 750 mm SonoPanels – stiff matrix 15% PZT-5H and soft matrix coverplated 15% PZT-5H versions. Also shown are selected 250 mm and 100 mm transducers produced in the program.

Track 2 focused on the design and initial evaluation of individual components and configurations for single layer SmartPanels (Figure 3). The primary developments were the design, fabrication, and evaluation of three styles of the net-shape-molded PZT accelerometers. The accelerometers were designed by NRL, fabricated by MSI, and tested at NRL. A 16 accelerometer panel was also designed, fabricated, and evaluated as a CAVES sensor candidate. Because the accelerometers were rigidly mounted to a stiff base, an unanticipated pressure sensitivity packaging issue was encountered. No other significant sensor-sensor or sensor-actuator coupling or EMI issues were found. A preliminary design for a 2-layer SmartPanel was also established (Figure 4).

The program also addressed defense and commercial systems applications for 1-3 piezocomposite SonoPanel transducers. These activities, referred to as Track 3, were carried out by MSI at no cost to the program or to the government and resulted in approximately \$250K in combined commercial and defense related sales during the term of the program.

The SmartPanel activities have continued in a DARPA/ONR follow-on program, entitled "SmartPanel Demonstrations Program" (Contract N00014-97-C-0236).

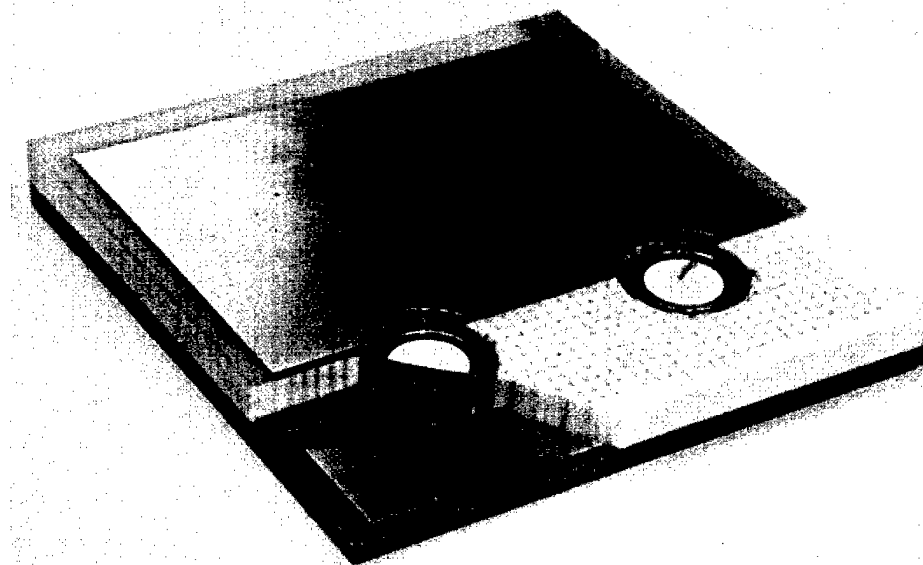


Figure 3. Cross section of 100 mm single layer SmartPanel.

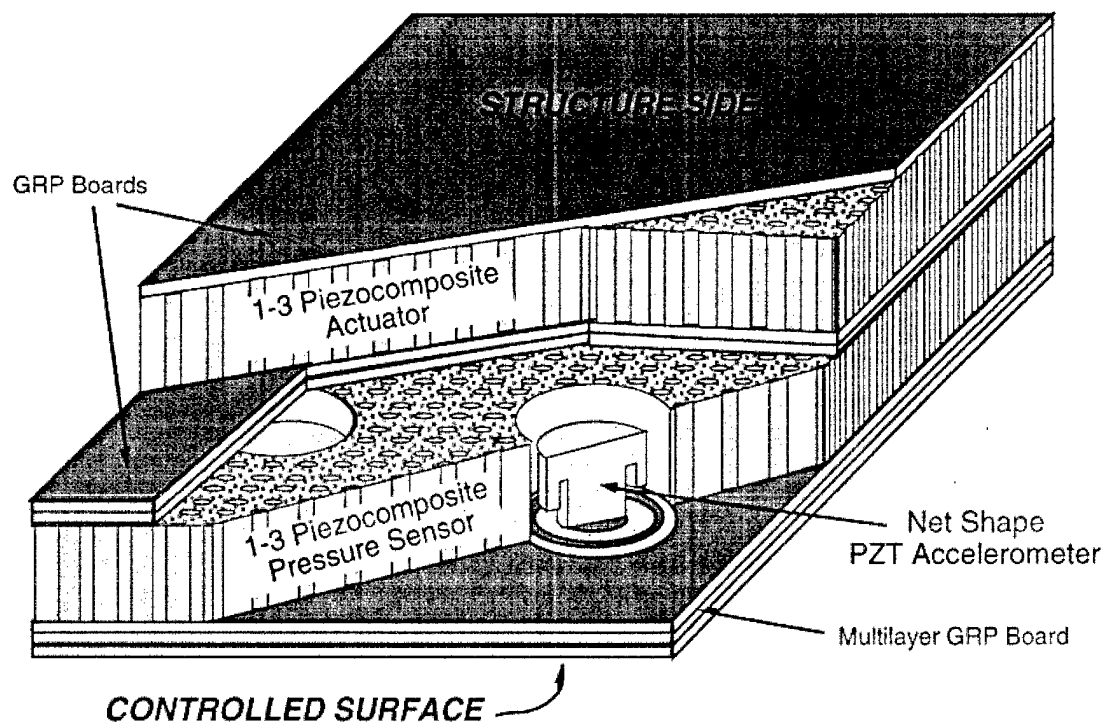


Figure 4. Preliminary design for 2-layer SmartPanel.

### Track 1: Next Generation 1-3 Composite Transducers

The goal of the Track 1 effort was to develop improved 1-3 composite SonoPanel transducers, ready for insertion into Navy systems. The manufacturing process is based on MSI's ceramic injection molding. The baseline SonoPanel configuration (Figure 5) consists of 1.1 mm diameter, PZT-5H (DOD Type VI) ceramic rods in a soft polyurethane matrix (Shore hardness: A-70). The composite contains 15% ceramic by volume, and the polyurethane matrix is loaded with 40 vol.% hollow plastic microspheres (~50  $\mu\text{m}$  dia.). Stiff, lightweight, copper-clad GRP coverplates (0.031" thick) are bonded to both faces of the composite with conductive epoxy which provides both electrical contact and efficient stress transfer of incident pressure waves to the ceramic elements. The edges of the composite are wrapped with a copper foil EMI shield, and the entire device is encapsulated in waterproof polyurethane. The effort to improve this design focused on the pressure stability, shock resistance, and conformability of the panel and on reducing cost.

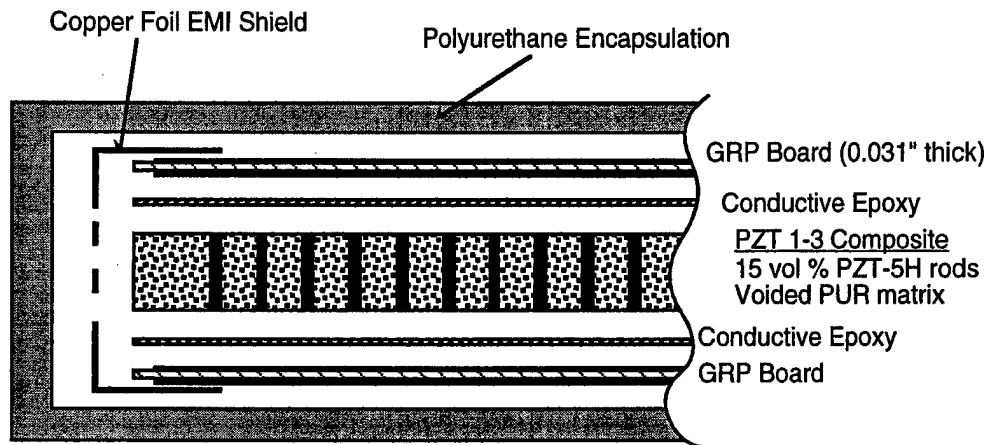


Figure 5. Baseline SonoPanel configuration.

### Track 1 - Task 1: New Transducer Panel Designs

A new injection molding tool was designed and built to produce ceramic preforms with 25 vol.% PZT content. The ceramic elements have a diamond shaped cross section, measuring 1.0 mm square and 9 mm long. There are 576 rods arranged in a uniform array on a 49 mm square baseplate. The increased volume fraction provides higher capacitance, greater transmit power, and increased actuator authority. Implementation of this tooling made a wide range of ceramic loading available. Both 15% and 25% preforms can be molded directly, while interdigitation of the as-molded preforms gives 30% and 50% volume fractions respectively. Figure 6 depicts the layout of these PZT composites. In addition, the selective removal of rods can be exercised to decrease the ceramic content.

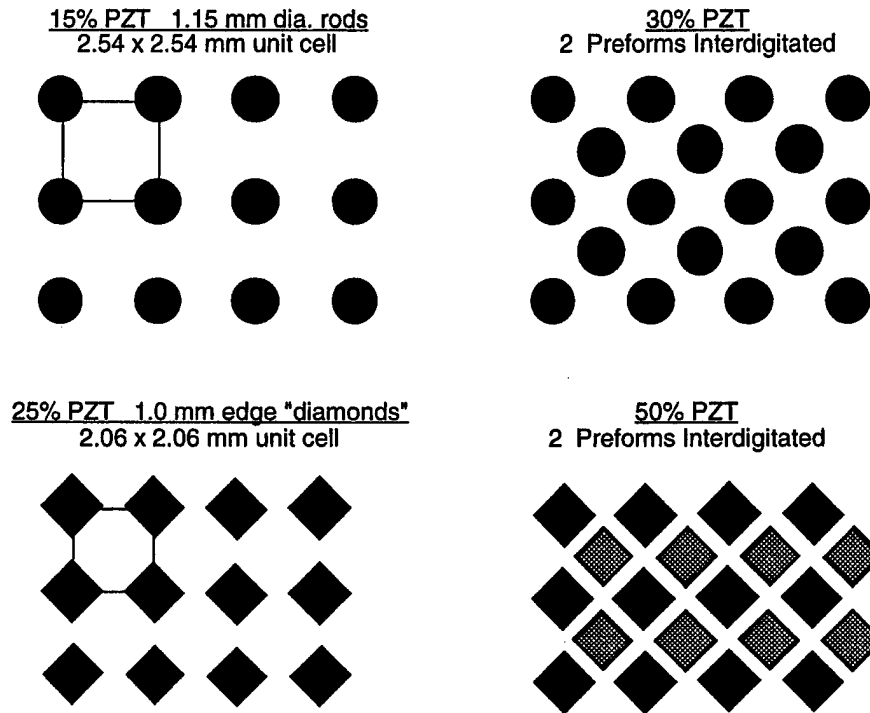


Figure 6: MSI's 15%, 25%, 30% and 50% composite configurations.

The conductive adhesive bond between the GRP coverplates and the composite core material in the baseline SonoPanel design was previously identified as a potential weak link with regard to high pressure and shock requirements for Navy applications. Therefore, an adhesive bond study was initiated where alternate adhesives, surface treatments, and bonding conditions were explored. Bonded composite test samples, 25 mm square, were prepared at MSI and tested in tension at UMass-Lowell.

Findings from this study led to modified surface preparation of the copper coverplates and the addition of a heat treatment stage during lamination to improve the adhesive bond.

As an alternate to the baseline SonoPanel design, stiff cast-in-place polyurethane coverplates were developed in conjunction with an "air matrix" composite. This design eliminated the conductive bond line completely. Also, the thermally softening polyurethane coverplates allow the composite to be formed to fit curved surfaces (Figure 7). Composite samples, preheated to approximately 60° C, have been curved to radii as small as 50 mm. The curvature is permanently retained after cooling to room temperature.

Initial in-water tests of the "air-matrix" design were promising, however the panels proved susceptible to damage by pressure and shock. Subsequent design iterations yielded a conformable, composite material with a solid matrix of stiff polyurethane (Shore D-80) and screen printed, silver epoxy electrodes (Figure 8).



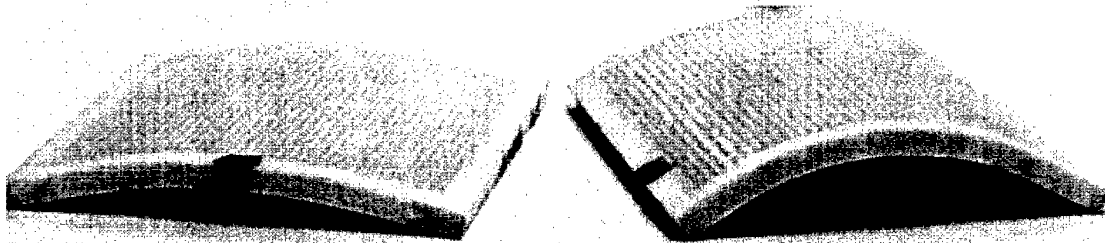


Figure 7. Stiff matrix 1-3 composite formed to a non-planar surface.

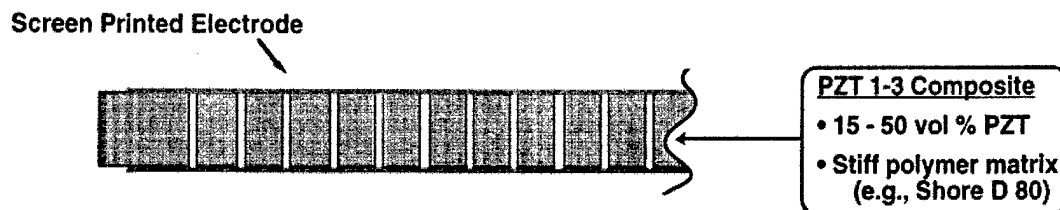


Figure 8. Stiff matrix 1-3 composite configuration.

Increasing production capacity and in-house polyurethane synthesis were two tasks undertaken to reduce the cost of SonoPanel fabrication. Sintering the ceramic preforms was determined to be a rate limiting step in the production process. A larger sintering furnace, capable of processing approximately 100 preforms per firing (an 8-fold increase over the existing furnaces) was designed, and two such furnaces were built (Figure 9). These bottom loading furnaces are less labor intensive to load and unload and can produce up to 1.75 m<sup>2</sup> of PZT preforms per week. An enhanced poling facility was installed which can accommodate the higher voltage and current required to pole PZT-4 ceramic and allows 16 preforms to be poled simultaneously (a 4-fold increase).

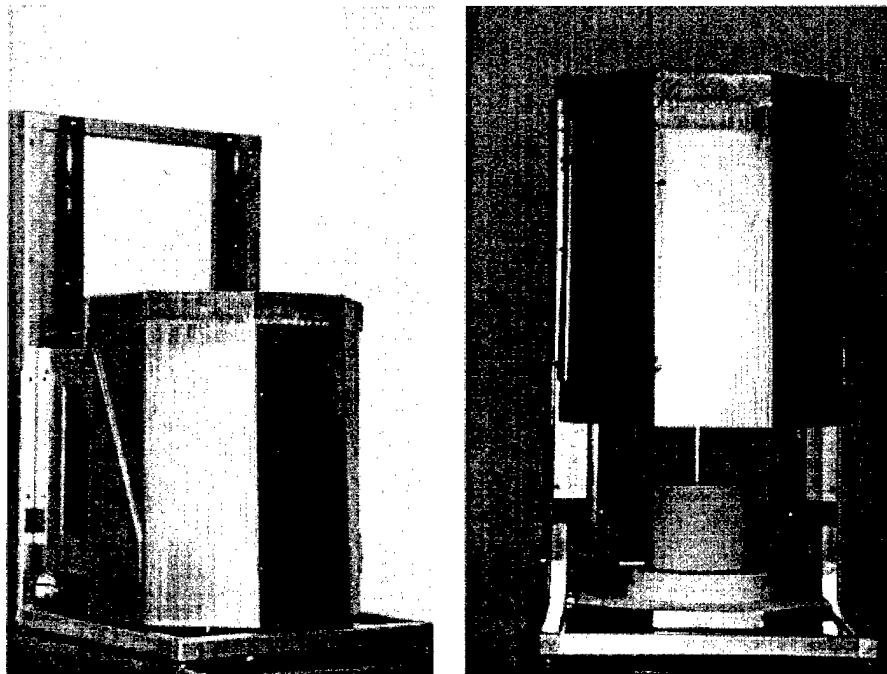


Figure 9. High capacity sintering furnaces provided an eight-fold increase in production capacity.

The polyurethane compound used for both the baseline SonoPanel composite matrix and the encapsulation of the finished panels was phased out of production by the manufacturer in 1996. Two commercially available substitute compounds from separate suppliers were identified as suitable replacements. In addition, a custom polyurethane compound was formulated from the base chemicals as part of the ongoing collaboration with the Plastics Department of the University of Massachusetts/Lowell. This poly-butadiene based urethane compound has comparable stiffness, durometer, and hydrolytic stability to the commercial polyurethanes and is less than one-half of the cost.

#### Track 1 - Task 2: PZT-4 Process Development

The ability of the 1-3 piezocomposite panels to withstand the hydrostatic pressure requirements of deep water deployment without depoling the ceramic elements was a primary program goal. The incorporation of a "hard" PZT formulation was undertaken to maximize the pressure stability and shock resistance of the panels. Commercially available PZT-4 powder (DOD Type II) was successfully compounded and molded with only minor adjustments to the manufacturing process previously established for PZT-5H (Figure 10). Subsequent testing showed excellent agreement between the injection molded material properties and typical properties for conventionally powder pressed ceramic (Table 1).

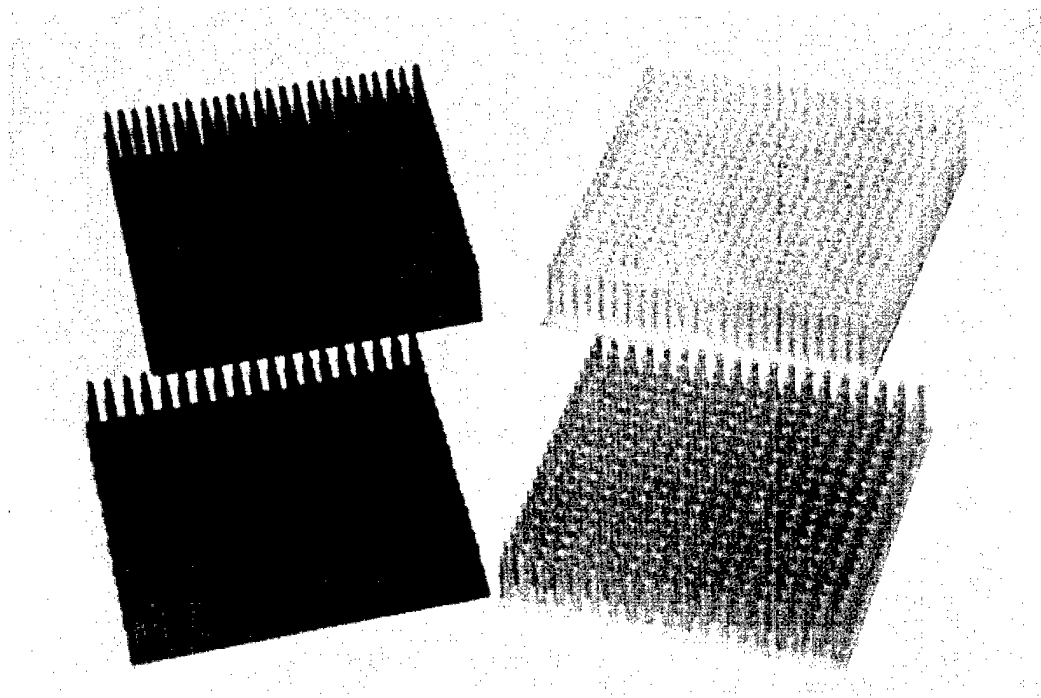


Figure 10. Injection Molded Preforms (clockwise from top left: 25 vol.% PZT-4, 25 vol.% PZT-5H, 15 vol.% PZT-5H, 15 vol.% PZT-4).

Table 1: Properties of Injection Molded and Conventionally Processed PZT Ceramics

	PZT-4 Inj. Molded	PZT-4 Pressed	PZT-5H Inj. Molded	PZT-5H Pressed
Dielectric Constant	1290	1300	3200	3400
Loss Tangent	0.005	0.004	0.020	0.025
$d_{33}$	294	285	685	593
$k_{33}$	0.70	0.70	0.75	0.75

The successful adaptation of the preform fabrication process to PZT-4 powder was followed by a similar effort to qualify alternate sources of PZT-5H powder. Powder samples were solicited from a number of vendors, and two additional, suitable sources of PZT-5H powder were identified (Table 2).

Table 2: Comparison of Ceramic Properties from Various Suppliers to the DOD Standard.

Property	DOD VI	Vendor 1	Vendor 2	Vendor 3
$K_{33}^T$	$3250 \pm 12.5\%$	3285	3184	3515
DF	$\leq 0.025$	0.0168	0.0197	0.0189
$Q_M$	$\geq 65$	73	62.3	66.9
density	$\geq 7.40$	7.52	7.601	7.682
$k_p$	$0.64 \pm 8\%$	0.666	0.672	0.598
$k_{31}$		0.391	.395	0.347
$d_{33}$	$575 \pm 15\%$	658	693	590
$d_{31}$		-272.8	-267.0	-233.7
$g_{33}$		22.62	24.60	18.98
$g_{31}$		-9.38	-9.48	-7.51
$N_p$	$1940 \pm 8\%$	1935	1953.9	2050.4
$s_{11}^E$		16.74	16.24	14.59
$s_{11}^D$		14.18	13.71	12.83
$Y_{11}^E$		5.975	6.159	6.856
$Y_{11}^D$		7.053	7.296	7.794

\* Measured 24 hrs after poling

#### Track 1 - Task 3: Fabricate 100 mm Transducers

A number of 1-3 composite transducers measuring 100 x 100 mm were fabricated. The parameters investigated included powder composition and source, ceramic volume fraction, matrix material and matrix stiffness, composite thickness, electrode type, and encapsulant. Composite transducers utilizing PZT-4 or PZT-5H ceramic in volume fractions ranging from 3.5% to 30%, in the standard or stiff matrix configurations were fabricated for in-water acoustic testing at NUWC-USRD. Complete descriptions of the individual transducer characteristics are presented in Appendix A.

#### Track 1 - Task 4: Test and Evaluate 100 mm Transducers

Twenty five different 100 x 100 mm configurations were selected for in-water, acoustic and environmental testing and evaluation at NUWC-USRD. The free field voltage sensitivity (FFVS) and transmit voltage response (TVR) of each transducer was measured in a frequency range between 1 kHz and 200 kHz. Typical FFVS and TVR results are shown in Figure 11 and Figure 12. RVS and TVR measurements were also made on selected samples at water temperatures of -4°C and 22°C, before and after exposure to hydrostatic pressures up to 6895 kPa, and prior to and after exposure to explosive shock. The conditions and results of all of these tests are presented in Appendices B through F.

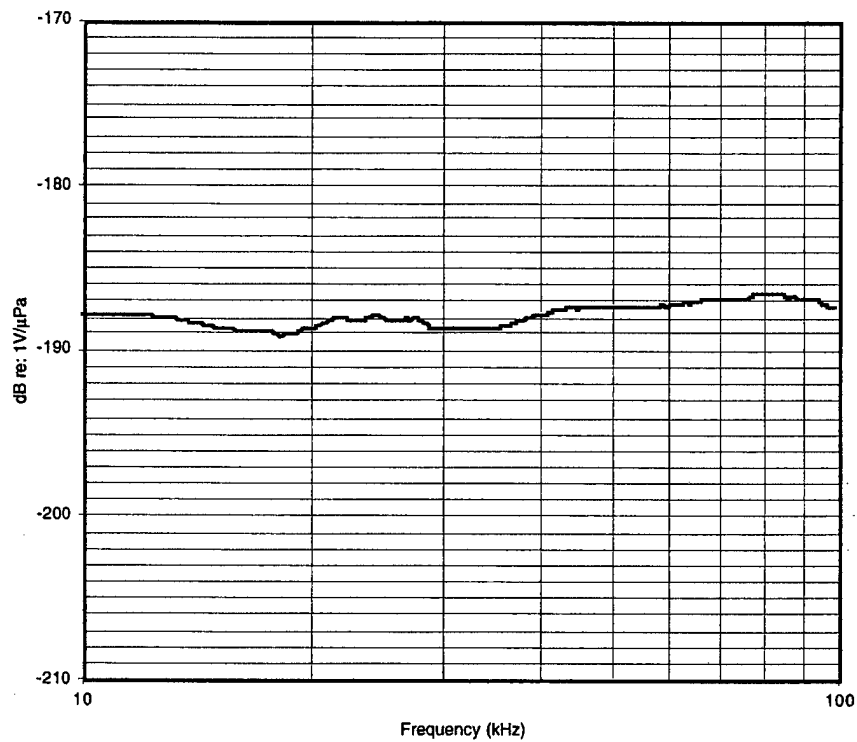


Figure 11. FFVS of 100 x 100 mm baseline SonoPanel design (Serial #4-30).



Figure 12. TVR of 100 x 100 mm baseline SonoPanel design (Serial #4-30).

### Track 1 - Task 5: Select 250 mm Panel Design

The results of the 100 mm transducer tests were used to select two SonoPanel configurations for further development and scaling to 250 x 250 mm transducers. The selected designs and their performance attributes are:

Design 1: 15% volume fraction, PZT-5H  
Soft PUR Matrix with 40 vol.% hollow plastic microspheres  
Bonded GRP Coverplates  
Attributes: Highest receive sensitivity  
Uniform receiving response - 10 Hz to 200 kHz  
Survived multiple explosive shocks

Design 2: 25% volume fraction, PZT-5H  
Stiff PUR Matrix with 20 vol.% hollow plastic microspheres  
Conductive Epoxy Electrodes  
Attributes: Conformal  
No adhesive bond  
Extremely pressure stable

Design 1 is the original baseline configuration with an enhanced bondline. As a receive element, this configuration has the highest sensitivity and most uniform response ( $\pm 1$  dB) from 10 Hz to 200 kHz. This configuration also survived multiple explosive shocks with no change in performance.

Design 2 uses 25% volume fraction ceramic in a stiff (Shore D-80) polyurethane matrix. Conductive epoxy electrodes are applied directly onto the faces of the composite, eliminating the coverplates and bondlines. This matrix material allows the composite to be formed under low heat and pressure to fit curved surfaces. The higher ceramic content yields increased transmit power output. This configuration also proved to be extremely pressure stable.

PZT-5H ceramic in the 1-3 configuration displayed no adverse performance effects after exposure to shock and pressure and is used in both designs.

### Track 1 - Task 6: Fabricate 250 mm Panels

The selected transducer designs were scaled to 250 x 250 mm panels using the established fabrication techniques. Two (2) transducers of each design were made available for in-water, acoustic evaluation at NRL-USRD.

### Track 1 - Task 7: Test and Evaluation of 250 mm Panels

Measurements on the 250 mm transducers were made in the NUWC-USRD Lake Facility. Free field voltage sensitivity, transmitting voltage response, and directional response (DR) in the horizontal plane were measured in the

frequency range 1.0 to 300 kHz at 30°C, and a depth of 3.9 meters. Sample FFVS and TVR test results are shown in Figure 13 and Figure 14. The complete set of results is presented in Appendix F.

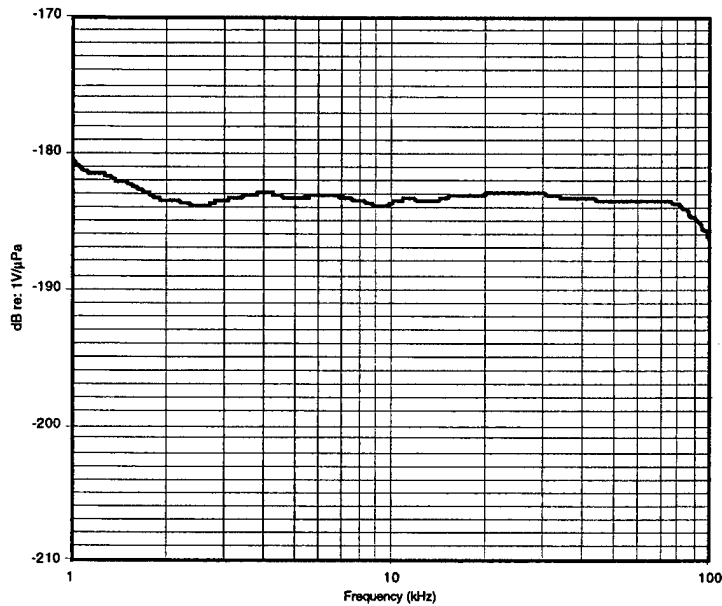


Figure 13. FFVS of 250 x 250 mm baseline SonoPanel design (Serial # 10-55).

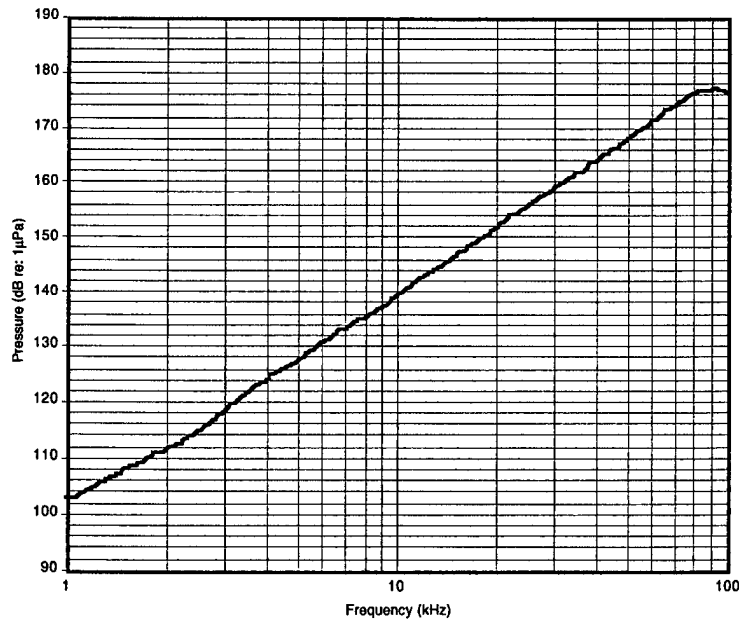


Figure 14. TVR of 250 x 250 mm baseline SonoPanel design (Serial # 10-55).

### Track 1 - Task 8: Large Area Transducer Test

Following the testing of the 250 x 250 mm transducers, both designs were scaled to 750 x 750 mm transducers (Figure 15). The 250 mm transducers were fabricated from a single sheet of cast composite. This was, however, the practical size limit of the standard fabrication process. The 750 mm panels were assembled by joining 9 individual 250 mm panels. For Design 1, the 9 panels were cast and coverplated independently then mounted on a single 750 mm GRP board and electrically connected together as shown in Figure 16. There was a single coaxial cable output from the panel. The 9 panels for Design 2 were connected using a spline and groove joint as shown in Figure 17. A continuous epoxy electrode was applied to both sides and a single coaxial cable output was used.

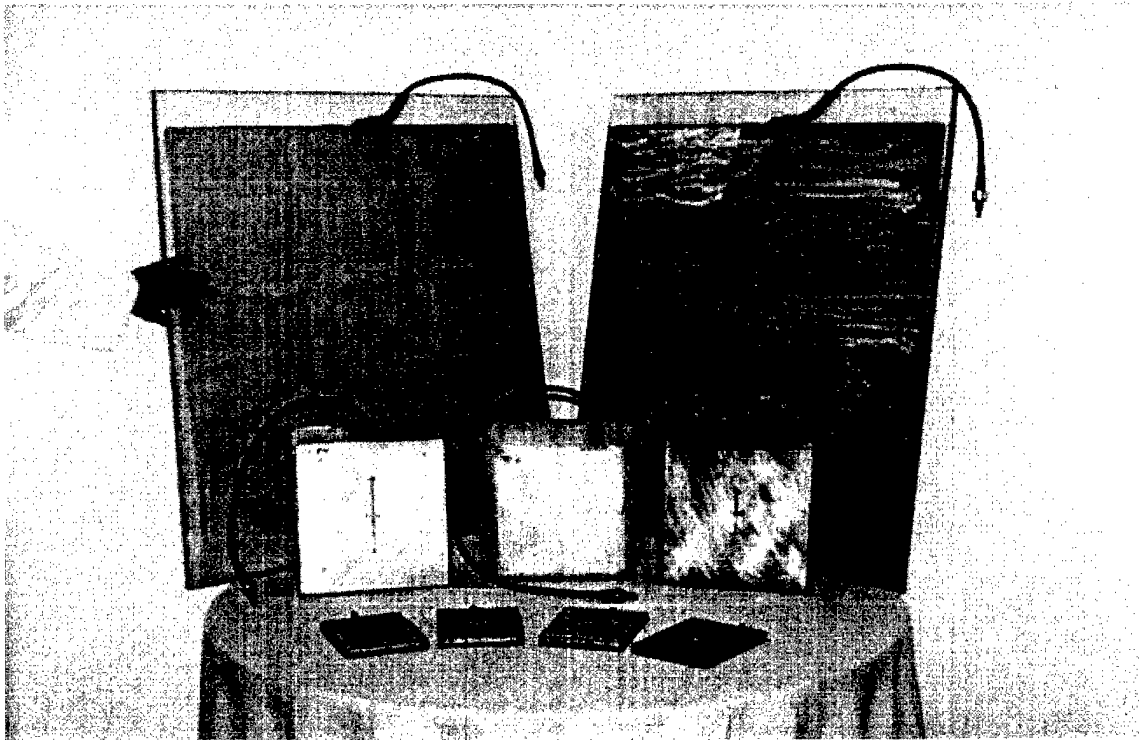


Figure 15. 100 x 100 mm, 250 x 250 mm, and 750 x 750 mm SonoPanel transducers.

As an intermediate step, a 200 x 200 mm panel of each design was fabricated by joining four (4) 100 x 100 mm panels by the aforementioned methods. These two 200 mm panels were fully tested and characterized before assembly of the large area panels commenced.



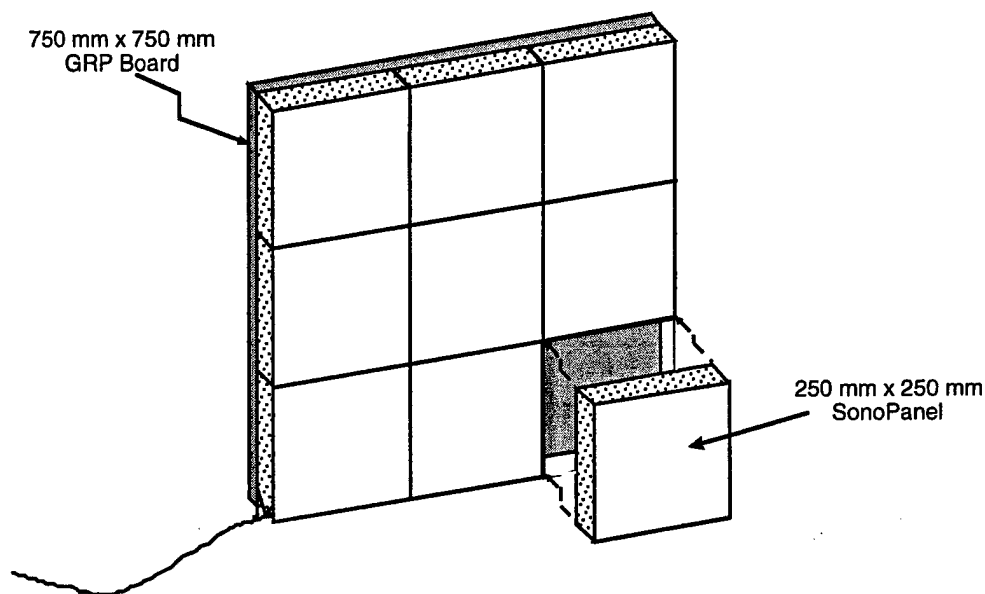


Figure 16. Construction of 750 x 750 mm SonoPanel, Design #1.

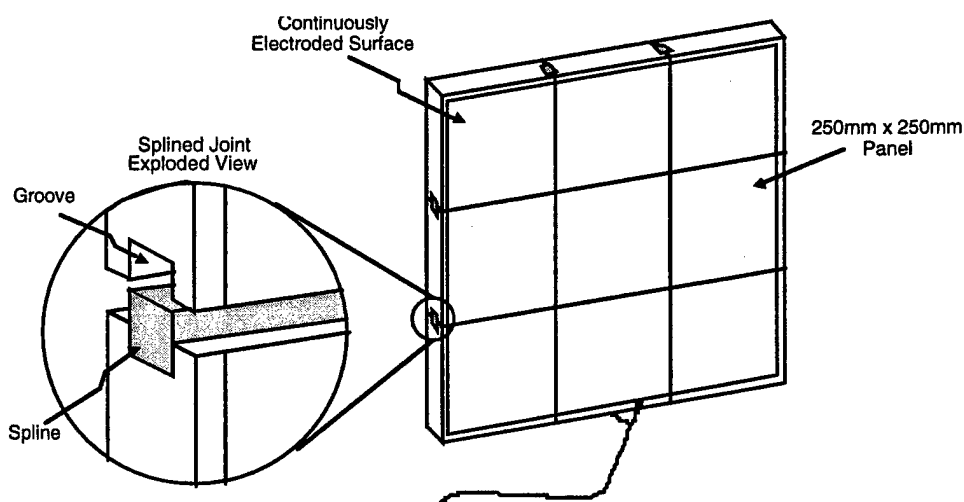


Figure 17. Construction of 750 x 750 mm SonoPanel, Design #2.

The 750 mm panels were encapsulated in waterproof polyurethane and made available for testing. Both panels underwent an open water acoustic evaluation at the NUWC-USRD Leesburg Lake Facility. In addition, acoustic evaluations at temperatures of 3 and 22°C, and pressures up to 6895 kPa were conducted at the NUWC-USRD Anechoic Tank Facility (ATF1). The FFVS and TVR data for both panels is shown in Figures 18 and 19. The complete test results are presented in Appendix G.

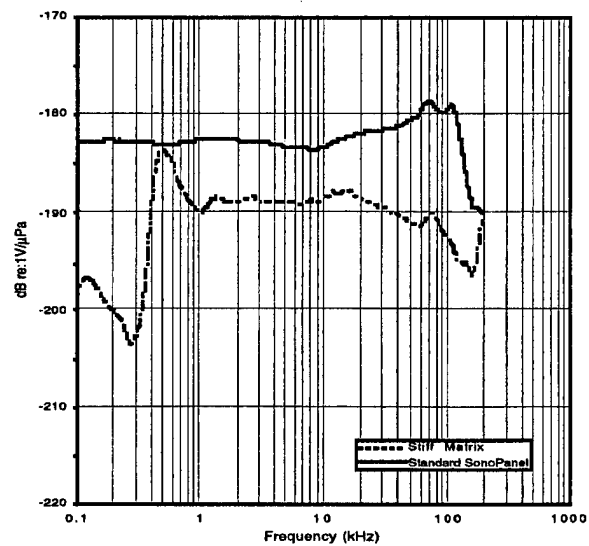


Figure 18. Free field voltage sensitivity measurements for the 750 x 750 mm standard and stiff matrix SonoPanels.

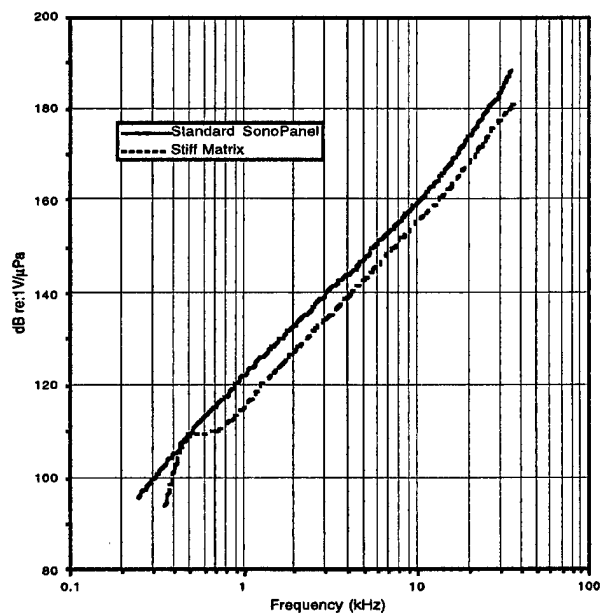


Figure 19. Transmit voltage response measurements for the 750 x 750 mm standard and stiff matrix SonoPanels.

## **Track 2: Smart Material Development**

The goal of the Track 2 effort was to develop 1-3 piezocomposite smart panels that combine sensing, actuation, and control for active surface control applications. Active acoustic control systems are recognized as representing one of the most promising new technologies for modifying or controlling the acoustical characteristics of surfaces. A simple smart vibration isolation mount can be constructed using an actuator layer and at least one sensor layer, where electronic feedback between the sensor and actuator can be used to adjust the dynamic response of the surface. For sound control, one implementation approach covers a surface of interest with an array of independently operating SmartPanels. Each panel contains an acoustic actuator layer and at least one sensor layer. Electronic feedback between the sensor and actuator (via an on-board controller) can be used to adjust the acoustic input impedance of the surface, and hence control its scattering and radiation efficiency.

Prior to the start of this program, NRL had described their underwater acoustic studies using active tiles fabricated from discrete components. These "ABC" panels included an actuator layer and acoustic sensor layers for obtaining the required area-averaged acoustic pressure and particle velocity. The actual test structure studied, called the NRL ABC array, contains 15 such panels on an air-backed steel structure. Each panel was independently controlled and a variety of acoustic surface impedance conditions were implemented. This study was highly successful, and the ABC platform continues to be used to study issues of multi-panel control.

Based on this prior technical success, the Track 2 effort focused on developing a replacement ABC-type panel with improved (closed loop) performance suitable for at-sea use at 10% the cost of the previous ABC panels.

### **Track 2 - SmartPanel Designs**

The initial design effort focused on a large area, low profile actuator with an array of uniformly distributed acceleration sensors and a single input-single output (SISO) controller to achieve a zero displacement controlled surface. The design utilized a single layer 1-3 piezocomposite actuator measuring 100 x 100 mm, and four (4) monolithic, piezoelectric accelerometers, spaced on 50 mm centers, imbedded in the piezocomposite panel. A custom fabricated multilayer circuit board allowed for the colocation of the sensors and actuator. A cut-away view of the panel design is shown in Figure 20.

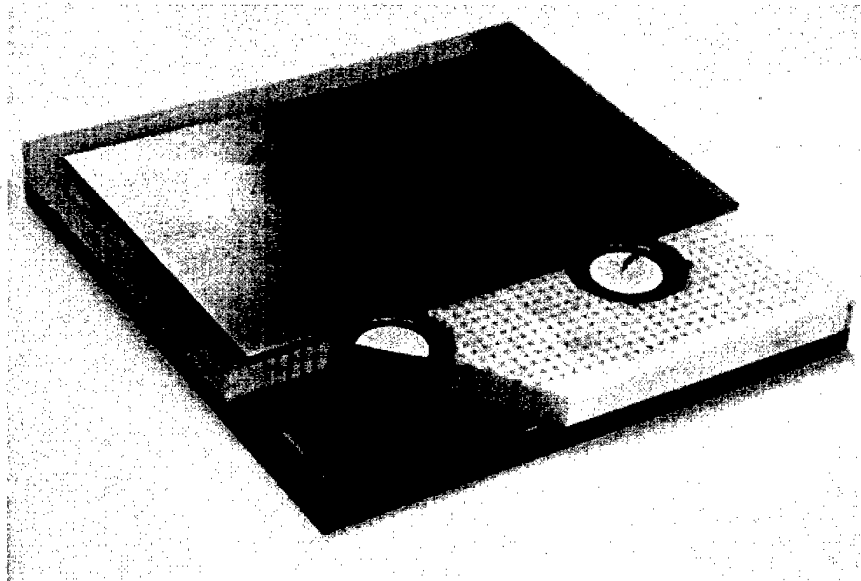


Figure 20. Cross section of 100 x 100 mm single layer SmartPanel.

The monolithic accelerometers used in this program are the result of a significant design and development effort undertaken by NRL. Conventional piezoelectric accelerometers consist of a mass supported by a piezoelectric element with electrodes. At frequencies much below the spring-mass resonance of this system, the seismic mass exerts a stress on the piezoelectric support which is proportional to the acceleration of the system. Under such a stress, the piezoelectric element delivers a charge or voltage to the electrodes which is proportional to its stress, and hence the acceleration.

The new monolithic accelerometer design fabricates the accelerometer as a single piece of piezoelectric ceramic. This one-piece construction containing both mass and charge-generating regions can be formed using ceramic injection molding.

Predictive models of accelerometer performance were developed which indicated that this approach would yield an accelerometer with greatly improved characteristics which could be manufactured at very low cost. These numerical models were then refined and used for both the accelerometer and the combined accelerometer-actuator system.

Prototypes of various configurations of this new accelerometer type were fabricated and tested (Figure 21). In all cases the key accelerometer parameters (sensitivity, longitudinal and transverse resonances, etc.) were highly predictable, and performance was found to be competitive with good instrumentation accelerometers. Unlike these instrumentation accelerometers, however, the monolithic accelerometer is sufficiently low cost that large inexpensive arrays can be assembled with a consequent outstanding improvement in performance.

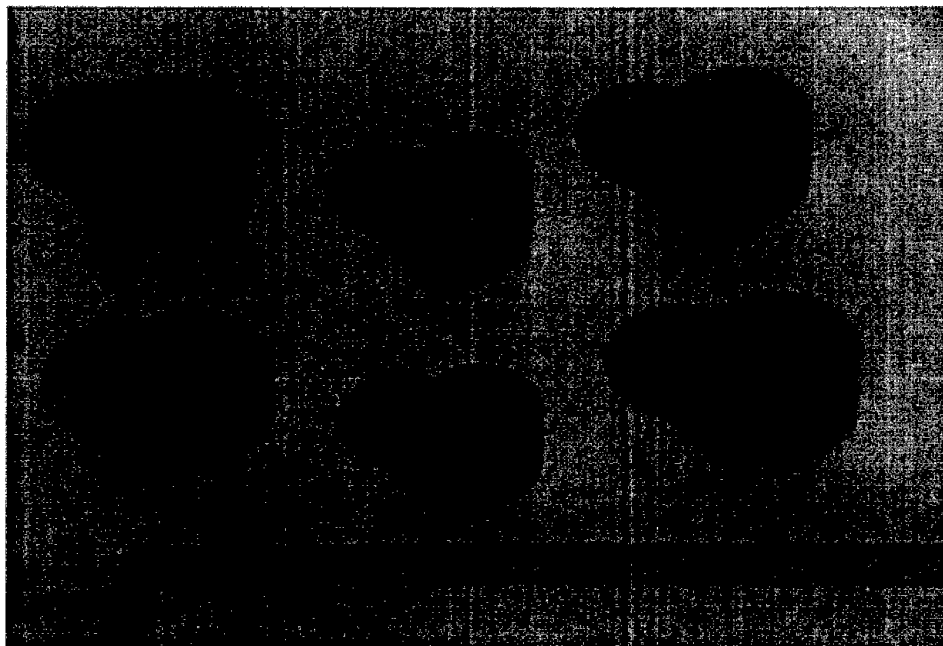


Figure 21. Monolithic piezoelectric accelerometers.

#### Track 2 - Prototype SmartPanel Fabrication

Three identical first generation single layer SmartPanel devices were constructed by MSI and evaluated by NRL. Issues such as cover resonances, EMI, and mechanical interferences were explored. Dynamic surface displacement measurements were also conducted by the Naval Air Warfare Center (NAWC).

These performance measurements led to a second generation test panel which contained a different sensor shielding arrangement in each of the accelerometer positions. The evaluation of this device resulted in modifications to the panel construction, intended to eliminate mechanical clamping of the panel surface.

Several new single layer panels were then fabricated for further study (Figure 22). These devices were tested at NRL by applying a broad band electrical signal to the actuator layer, and measuring the voltage generated by the accelerometers. The surface of the device was also scanned using Laser Doppler Vibrometry (LDV). The velocity uniformity was found to be very good, and the velocity measured by the internal monolithic accelerometers was in excellent agreement with that measured by the LDV, indicating that the internal accelerometers very accurately represent the motion of the top cover.

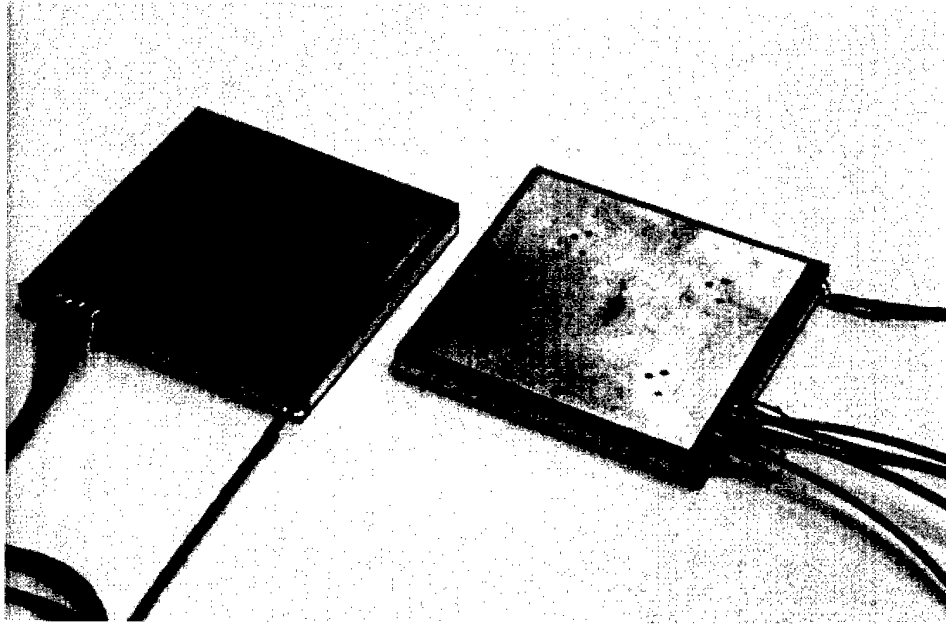


Figure 22. 100 mm x 100 mm single layer SmartPanels.

A single layer panel was then used in a control study to explore the issues involved in using this simple unit as a vibration-reduction mount. The mounting surface was vibrated under broadband excitation. Without the control system operating this vibration transferred to the front surface of the above unit with little loss. The signal from the accelerometers was then connected to the input of a controller. The controller was designed to use this sensor input signal to attempt to force the actuator layer to reduce the motion of the top surface. The controller performance criteria imposed was 20 dB reduction over the frequency range 1 to 4 kHz. When the system was then operated in real time, the performance found was in excellent agreement with that designed over the entire measured (extended) frequency range with no apparent instabilities (Figure 23).

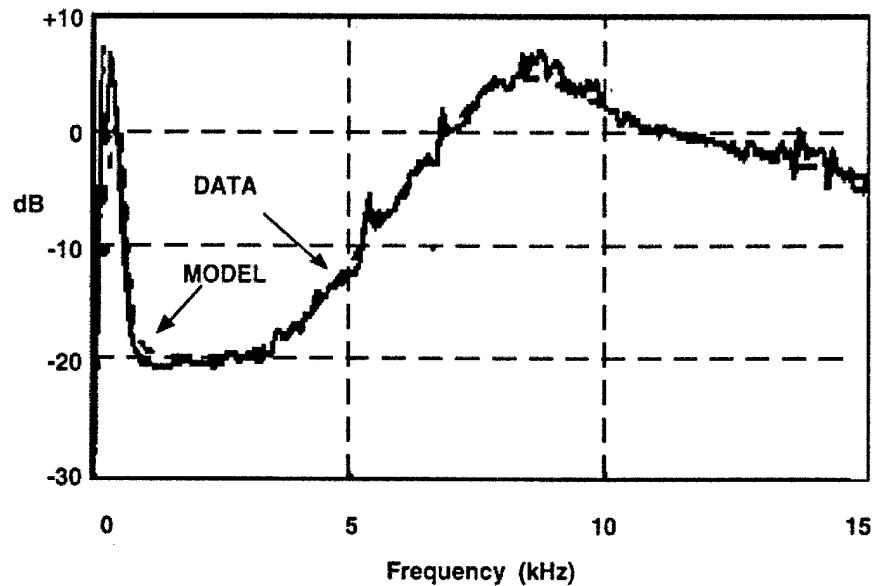


Figure 23. 20 dB broad band vibration reduction using single layer SmartPanel.

Double layer, 100 x 100 mm SmartPanels were constructed utilizing two layers of 1-3 composite, one layer configured as a pressure sensor and the second layer as the actuator. The accelerometer array was incorporated into the pressure sensor. The two layer panel was designed principally for use as a low-cost high-performance version of the ABC panel. The devices were tested in a water filled evaluation tank and the pressure and velocity coupling were measured. The results were excellent over the frequency band of interest (1 to 4 kHz). The pressure coupling level is high with a frequency response closely following a 12 dB/octave slope as expected for a piezo-ceramic projector in the nearfield. The velocity coupling is also quite good. Each of the four accelerometer outputs closely follows the expected -24 dB/octave slope. The two layer panel design was then scaled to 250 x 250 mm as shown in Figure 24.

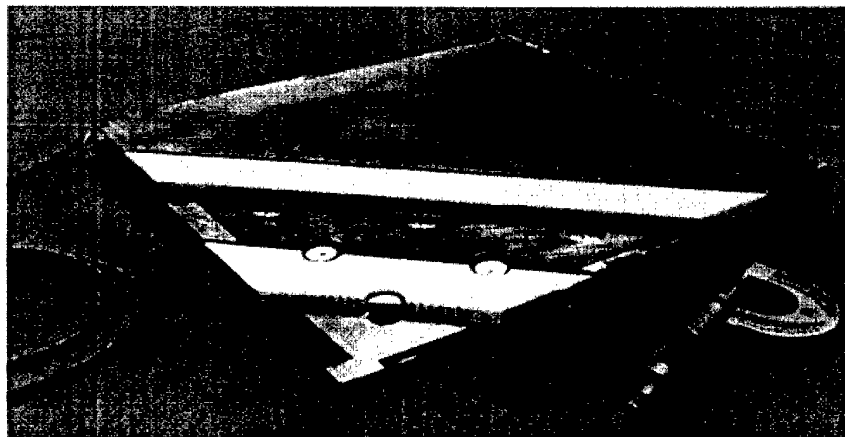


Figure 24. 250 x 250 mm two layer SmartPanel cut-away view.

### Track 3: Systems Applications

The goal of the Track 3 effort was the development of defense and commercial systems applications for 1-3 composite transducer materials. Applications development was undertaken by all of the program team members. This effort resulted in approximately \$250K in combined commercial and defense related sales during the term of the program.

#### Track 3 - Task 1: DoD Applications

The effort to identify potential DoD applications for 1-3 composite transducers resulted in the development and sale of prototype devices for use in systems related to underwater acoustic measurements, large area hydrophones, large area projectors, active surface control, underwater imaging and mine detection. Two examples of DoD sonar applications are shown in Figures 25 and 26.



Figure 25. Broad band high frequency acoustic imaging array.



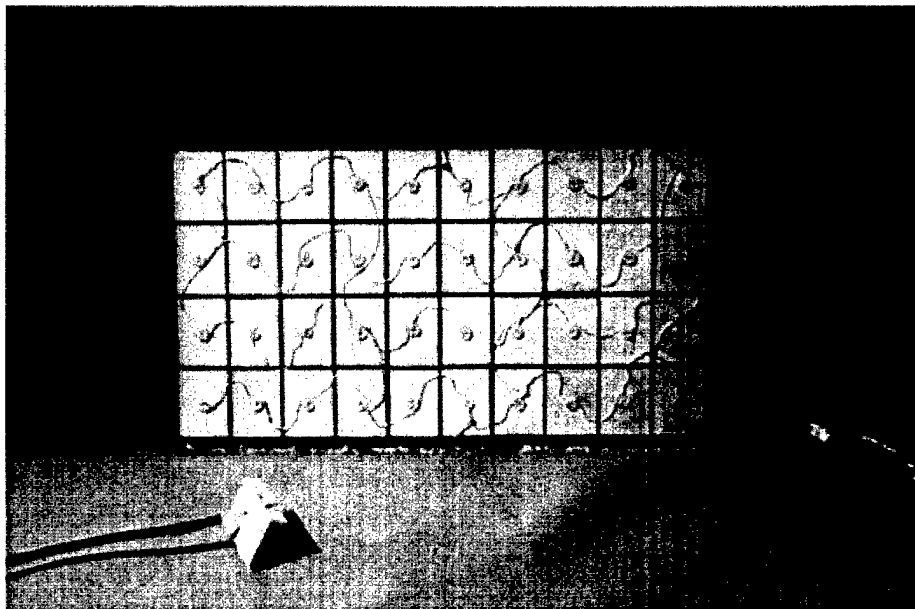


Figure 26. Multi-element mine hunting array.

### Track 3 - Task 2: Commercial Applications

The effort to identify potential commercial applications for 1-3 composite transducers resulted in the development and sale of prototype devices for use in systems related to underwater oil exploration (Figure 27), machinery vibration control (Figure 28), underwater imaging and platform inspection, bearing determination (Figure 29), fish finders, fish farming, and aircraft vibration and noise suppression.



Figure 27. High temperature/high pressure transducers for deep well acoustic measurements.

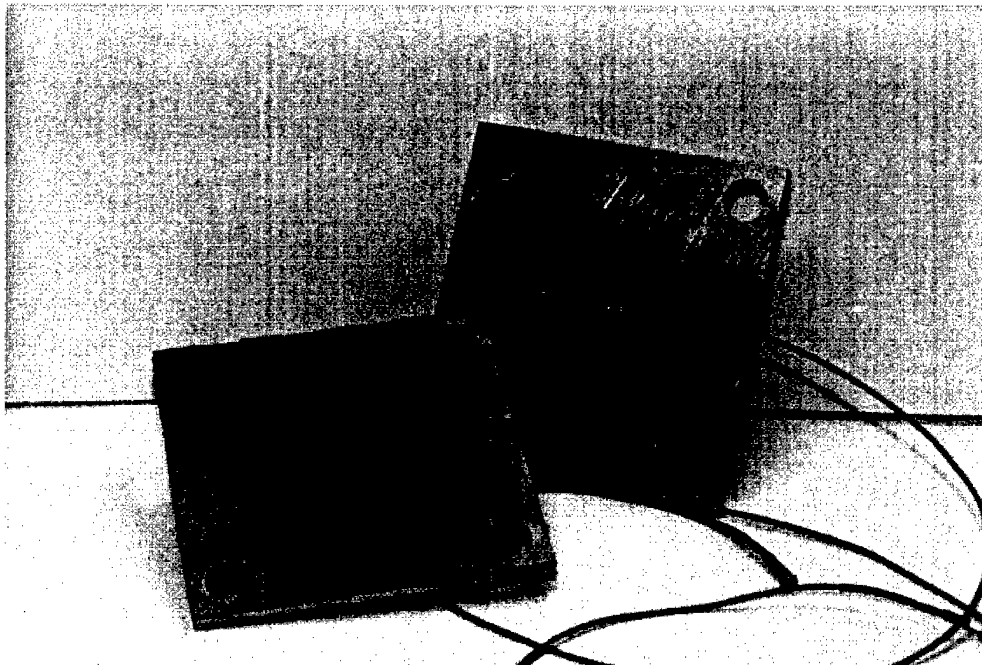


Figure 28. Machinery mount force sensors.

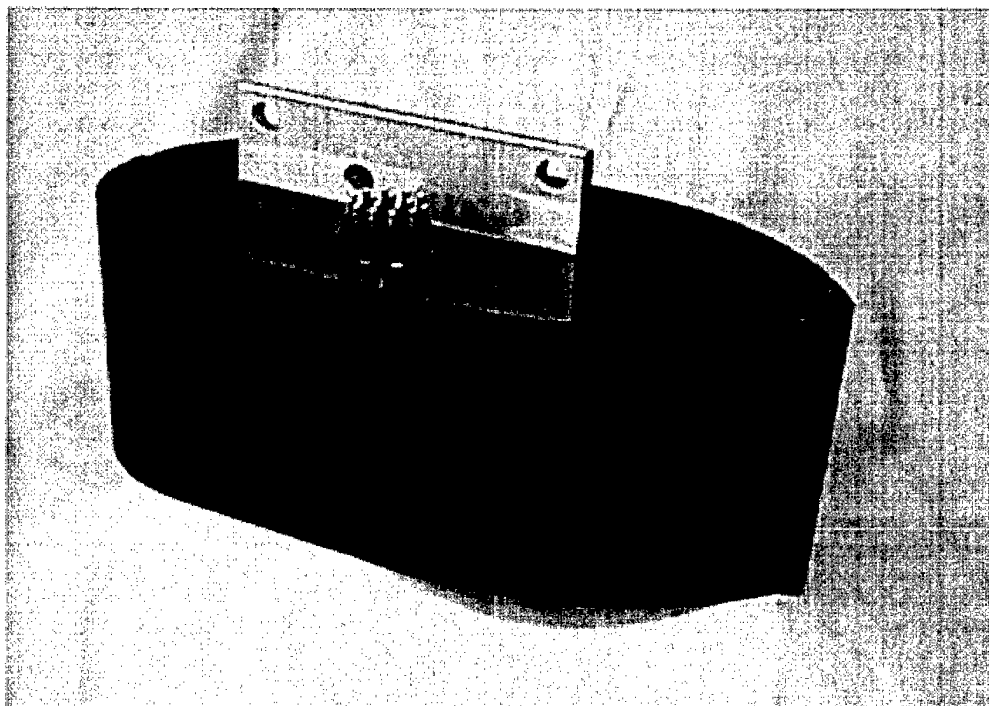


Figure 29. Directional transmit/receive array for bearing determination.

## **Appendices**

Appendix A: SonoPanel and SmartPanel Serial Numbers and Descriptions

Appendix B: USRD Calibration Memorandum No. 0615, August 18, 1995

Appendix C: USRD Calibration Memorandum No. 0695, December 5, 1995

Appendix D: USRD Calibration Memorandum No. 0727, April 5, 1996

Appendix E: USRD Calibration Memorandum No. 0779, April 29, 1996

Appendix F: USRD Calibration Memorandum No. 0851, October 2, 1996

Appendix G: Effects of Temperature and Pressure on the Acoustic Properties  
of Large 1-3 Piezocomposite Panels - Final Report. R.Y. Ting,  
Contract No. N66604-98-M-0722, May 1998.

# Appendix A

SmartPanels:

	Serial #	Layers	Dimensions (in)	Notes
1.	SP 4-1	1	4x4	Prototype single layer SmartPanel
2.	SP 4-2	1	4x4	Faceplates and accelerometers clamped by bonding agent
3.	SP 4-3	1	4x4	Surface displacement measurements (laser vibrometry) (I. Perez)
4.	SP 4-4	1	4x4	Multiple shielding configurations investigated, laser vibrometry tests
5.	SP 4-5	1	4x4	Accelerometers installed in faceplated composite, clamping eliminated
6.	SP 4-6	1	4x4	Shielding study, laser vibrometry
7.	SP 4-7	1	4x4	Vibration reduction study, 20 dB reduction demonstrated
8.	SP 4-8	2	4x4	Prototype double layer SmartPanel
9.	SP 10-1	2	10x10	Cross section display panel
10.	SP 4-9	2	4x4	Base strain issue revealed
11.	SP 4-10	2	4x4	Strain relieved circuit board, CP-3 accelerometers used

<sup>1</sup>Composite thickness is 0.250 in. unless otherwise noted

<sup>2</sup>EN-2, <sup>3</sup>H566, <sup>4</sup>EN-13, <sup>5</sup>KG-2

<sup>6</sup>Conductive epoxy

<sup>7</sup>Copper mesh w/ epoxy

<sup>8</sup>Double layer (0.500 in. thick)

# Appendix B



DEPARTMENT OF THE NAVY  
NAVAL UNDERSEA WARFARE CENTER  
1176 HOWELL STREET  
NEWPORT RI 02841-1708



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P O BOX 568337  
ORLANDO FL 32856-8337

IN REPLY REFER TO:

3965

Ser X72500-0615R

18 AUG 1995

USRD CALIBRATION MEMORANDUM NO. 0615

Subj: MEASUREMENTS ON 4A-8, 4D-1, 4H-1, 4H-2, AND 430 MODEL TRANSDUCERS

Ref: (a) Request for Calibration, 6 Jun 1995  
(b) NUWC-USRD Job Order No. H27512

Encl: (1) USRD Charts 1 through 96 and Table 1  
(2) USRD Drawing 5964

1. Measurements on the subject transducers were made in the Anechoic Tank Facility during the period 10 through 24 July 1995 in accordance with reference (a). Funds for this service were provided by reference (b).

2. Free-field voltage sensitivity (FFVS), transmitting voltage response (TVR), and directional response (DR) in the horizontal (XY) plane were measured in the frequency range 10 to 100 kHz, at the water temperatures 4 and 22°C, and at hydrostatic pressures to 6895 kPa (703.1 m). Conditions and results of the measurements are shown in enclosure (1).

3. Orientation was as described for a piston in enclosure (2). An arrow on the face of the transducer was in the +Z axis and the cable exited in the -Z direction except where otherwise noted.

*A.E. Paolero*  
A. E. PAOLERO  
Project Leader

*R.M. Drake*  
R. M. DRAKE  
Head, Acoustic Measurements T&E Branch

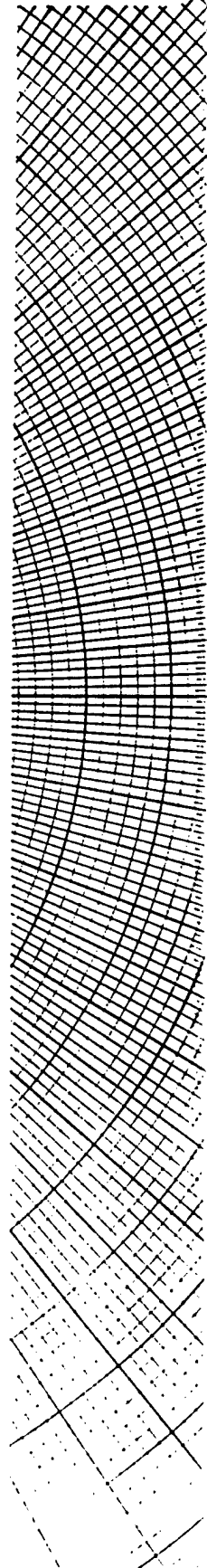
Copy to:  
NRL (Code 7135, T. Howarth)  
NUWC-USRD (Code 251, R. Ting)  
(Code 2582)

Further dissemination only as directed by  
Commanding Officer, Naval Undersea Warfare  
Center (18 AUG 1995 ) or higher DoD  
authority.

330°  
80°  
30°  
01C TANK  
995

TABLE 1  
DATA DIRECTORY

	CHART
Transducer	
.....	1
.....	2
.....	3-12
Transducer	
.....	13
.....	14
.....	15-24
.....	25
.....	26
.....	27-36
Transducer	
.....	37
.....	38
.....	39-48
.....	49
.....	50
.....	51-60
Transducer	
.....	61
.....	62
.....	63-72





330°  
330°

340°  
340°

350°  
350°

0°  
0°

10°  
10°

20°  
20°

330°  
30°

USRD NO: 0615-8  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

-10

-20

-30

-40

32°  
40°

31°  
50°

30°  
60°

29°  
70°

28°  
80°

27°  
90°

26°  
10°

25°  
11°

24°  
12°

23°  
13°

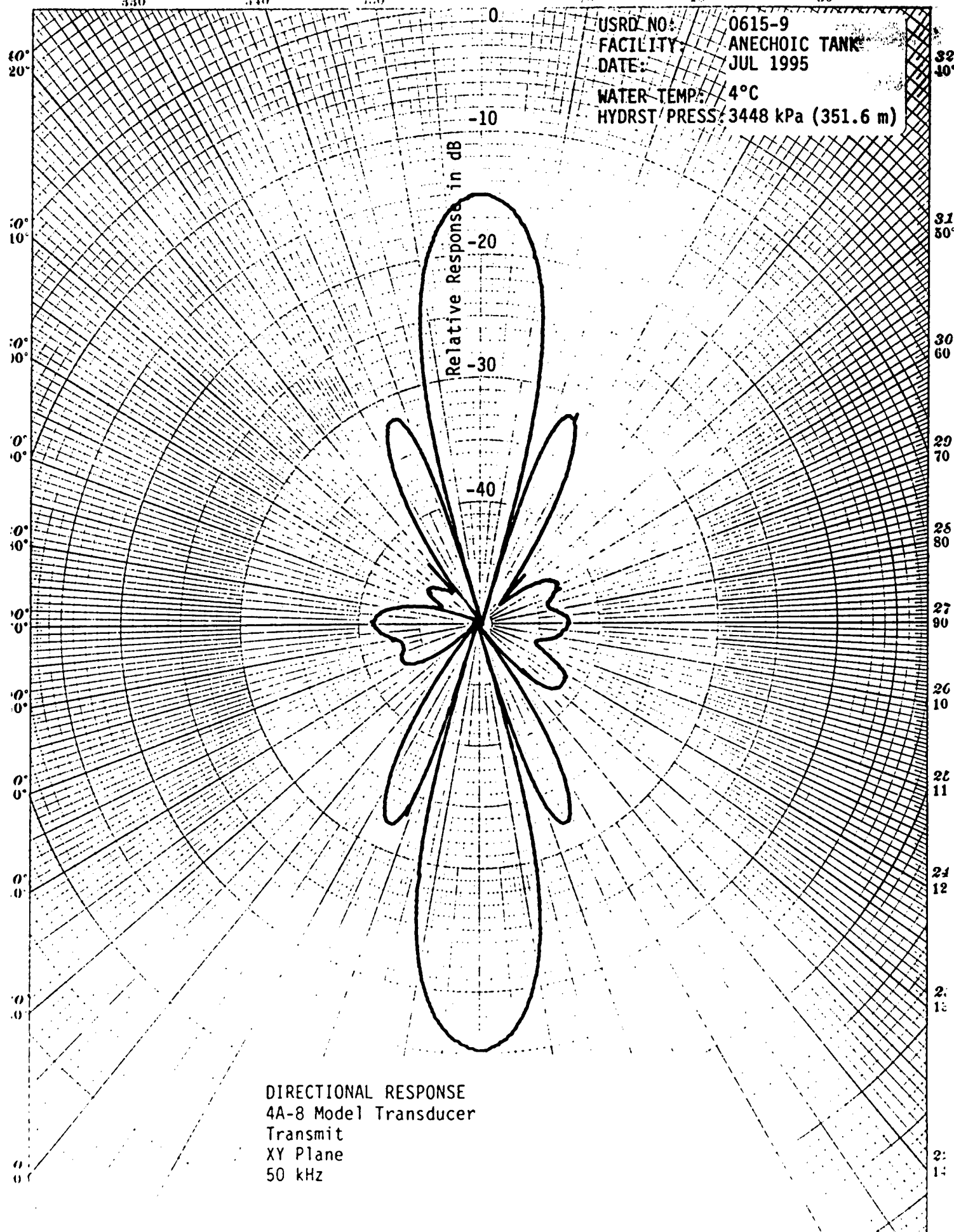
22°  
14°

DIRECTIONAL RESPONSE  
4A-8 Model Transducer  
Transmit  
XY Plane  
65 kHz

8

30°  
330°30°  
330°30°  
330°30°  
330°30°  
330°30°  
330°

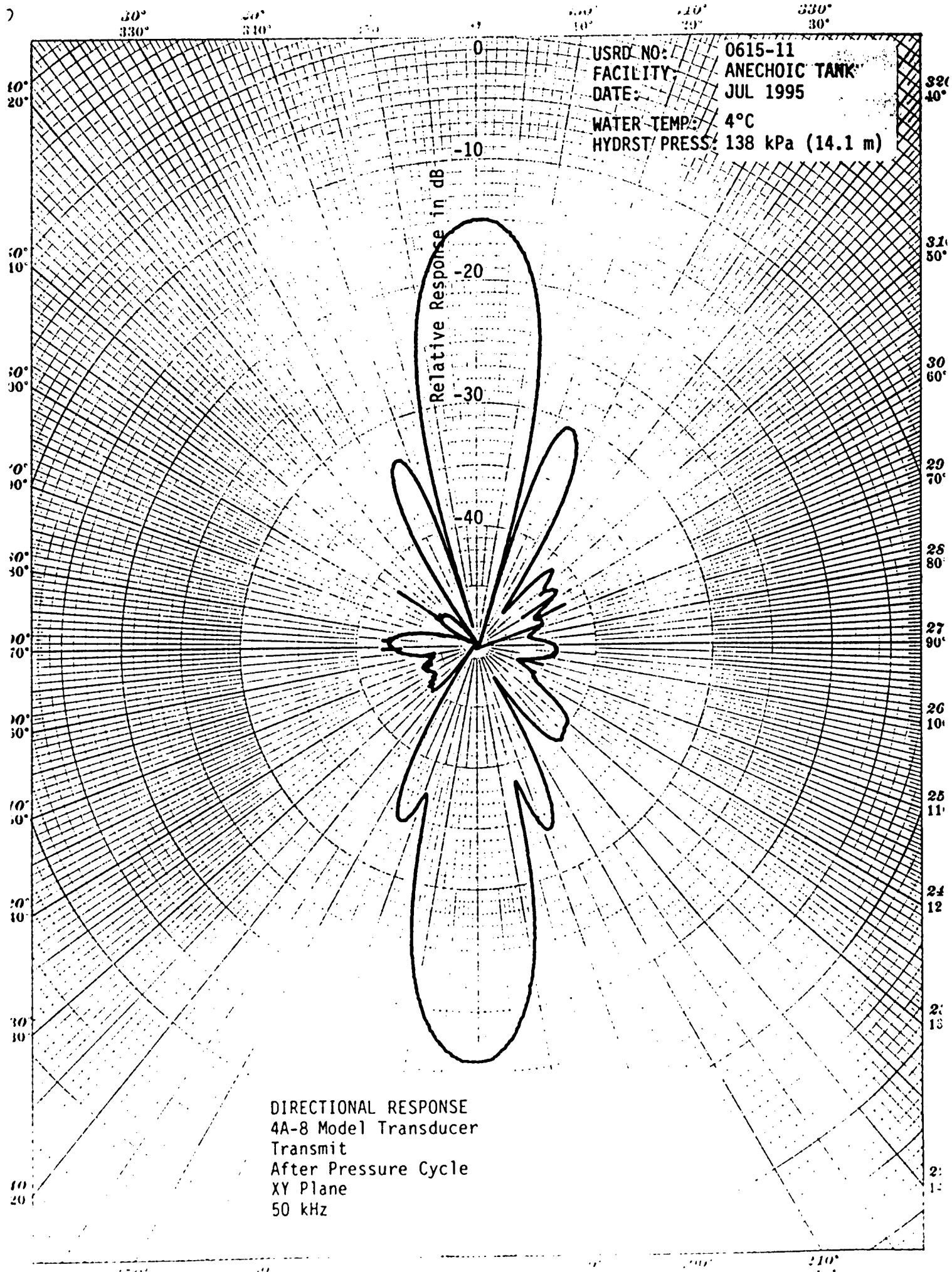
USRD NO: 0615-9  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)



USRD NO: 0615-10  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
4A-8 Model Transducer  
Transmit  
XY Plane  
65 kHz



USRD NO: 0615-11  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
4A-8 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
50 kHz

32  
40  
31  
50  
30  
60  
29  
70  
28  
80  
27  
90  
26  
10  
25  
11  
24  
12  
23  
13  
22  
14  
21  
15

330°  
330°

310°  
310°

270°  
270°

150°  
150°

90°  
90°

30°  
30°

USRD NO: 0615-12  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4A-8 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
65 kHz

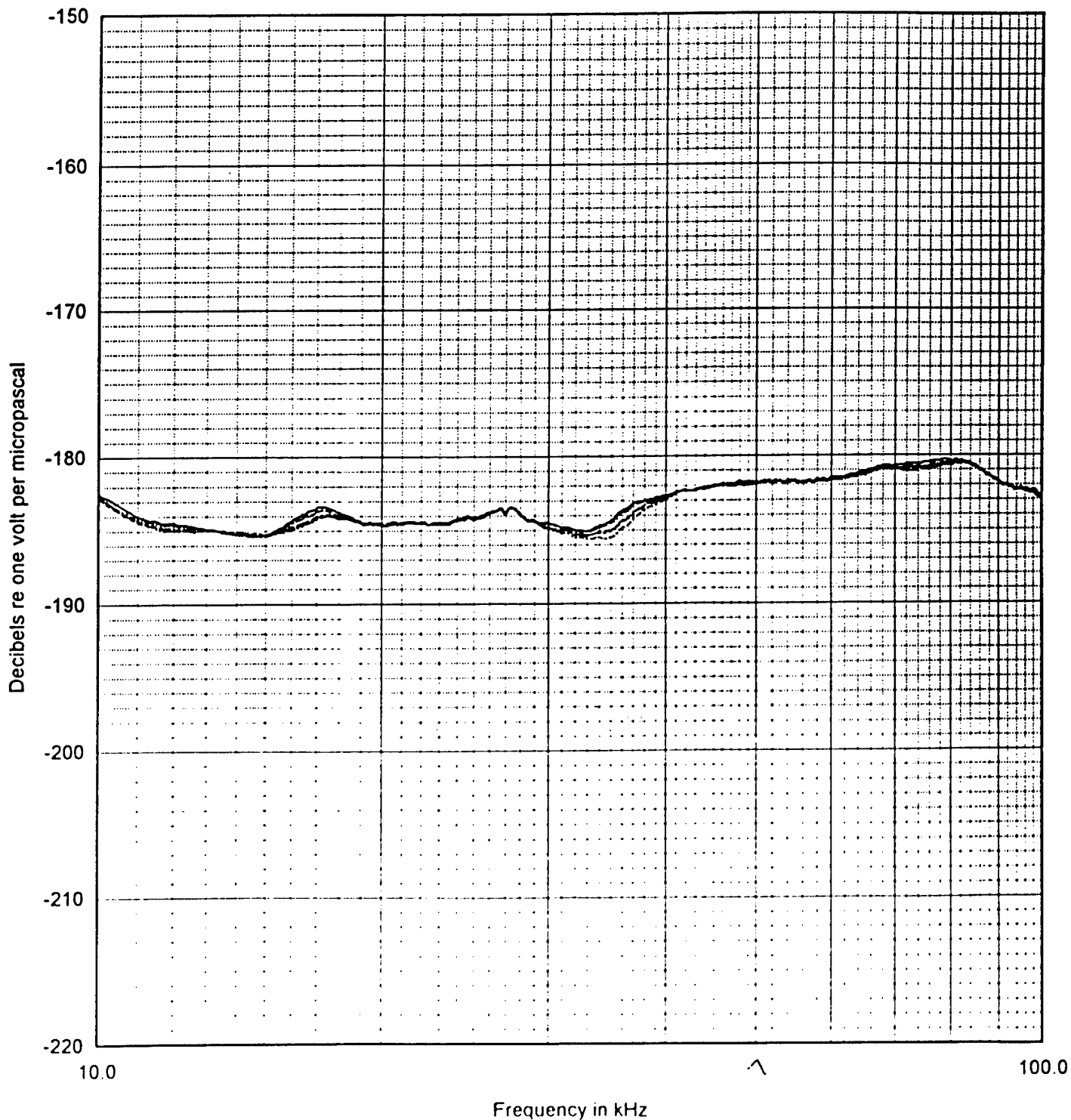
## FREE-FIELD VOLTAGE SENSITIVITY

4D-1 Model Transducer

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle



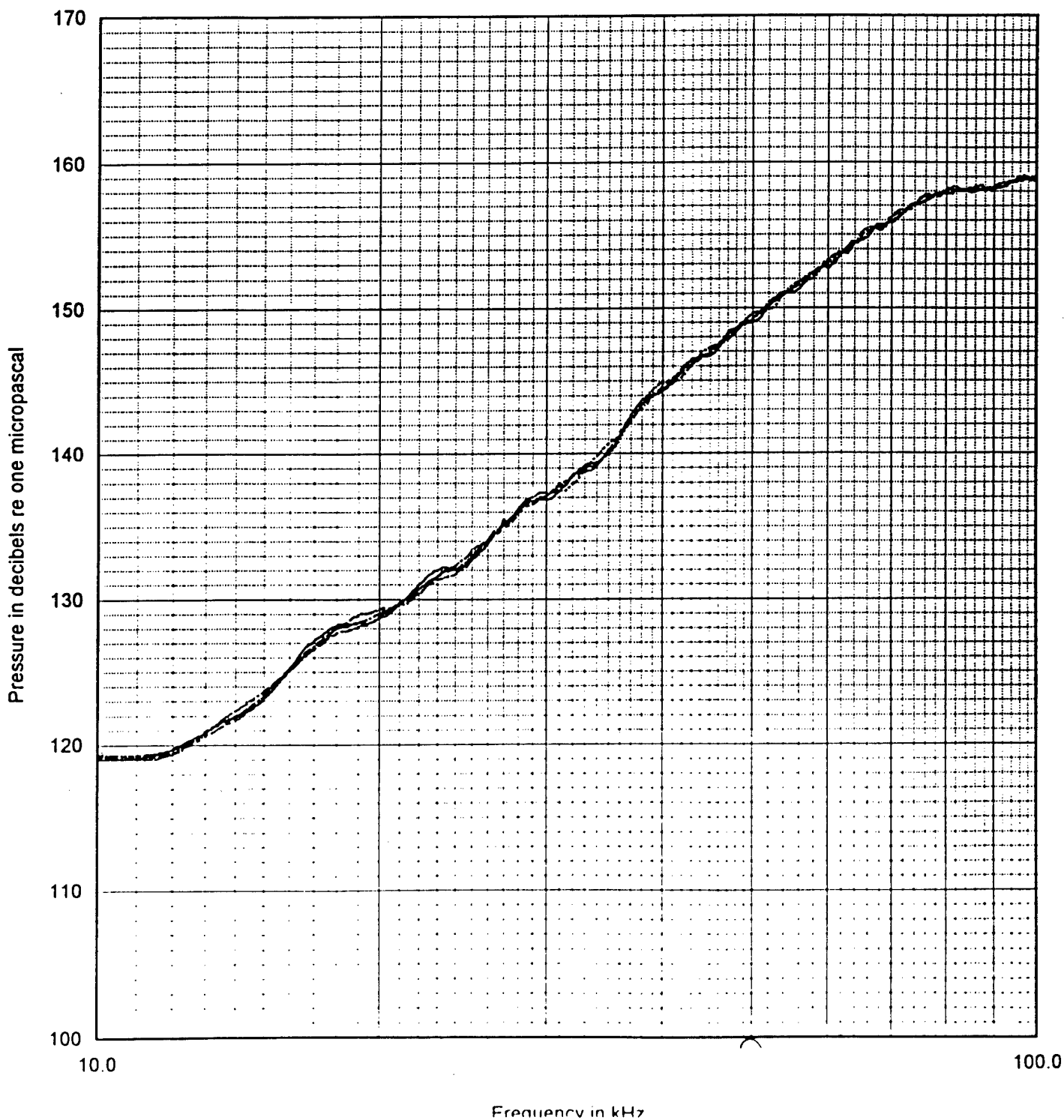
## TRANSMITTING VOLTAGE RESPONSE

4D-1 Model Transducer

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle





30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

USRD NO. 0615-15  
FACILITY ANECHOIC TANK  
DATE JUL 1995  
WATER TEMP 4°C  
HYDRST PRESS 138 kPa (14.1 m)

Relative Response in dB

0

-10

-20

-30

-40

330°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
50 kHz

150°  
300°

160°  
310°

170°  
320°

180°  
330°

190°  
340°

200°  
350°

210°  
360°



30°  
330°

30°  
340°

30°  
350°

0

330°  
10°

330°  
20°

330°  
30°

USRD NO: 0615-16  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

-10

-20

-30

-40

330°  
40°

330°  
50°

330°  
60°

330°  
70°

330°  
80°

330°  
90°

330°  
100°

330°  
110°

330°  
120°

330°  
130°

330°  
140°

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
65 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0615-17  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDROST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

-10

-20

-30

-40

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0615-18  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

-10

-20

-30

-40

320  
40°

310  
50°

300  
60°

290  
70°

280  
80°

270  
90°

260  
100°

250  
110°

240  
120°

230  
130°

220  
140°

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

170°  
170°

160°  
160°

150°  
150°

140°  
140°

130°  
130°

120°  
120°

110°  
110°

2

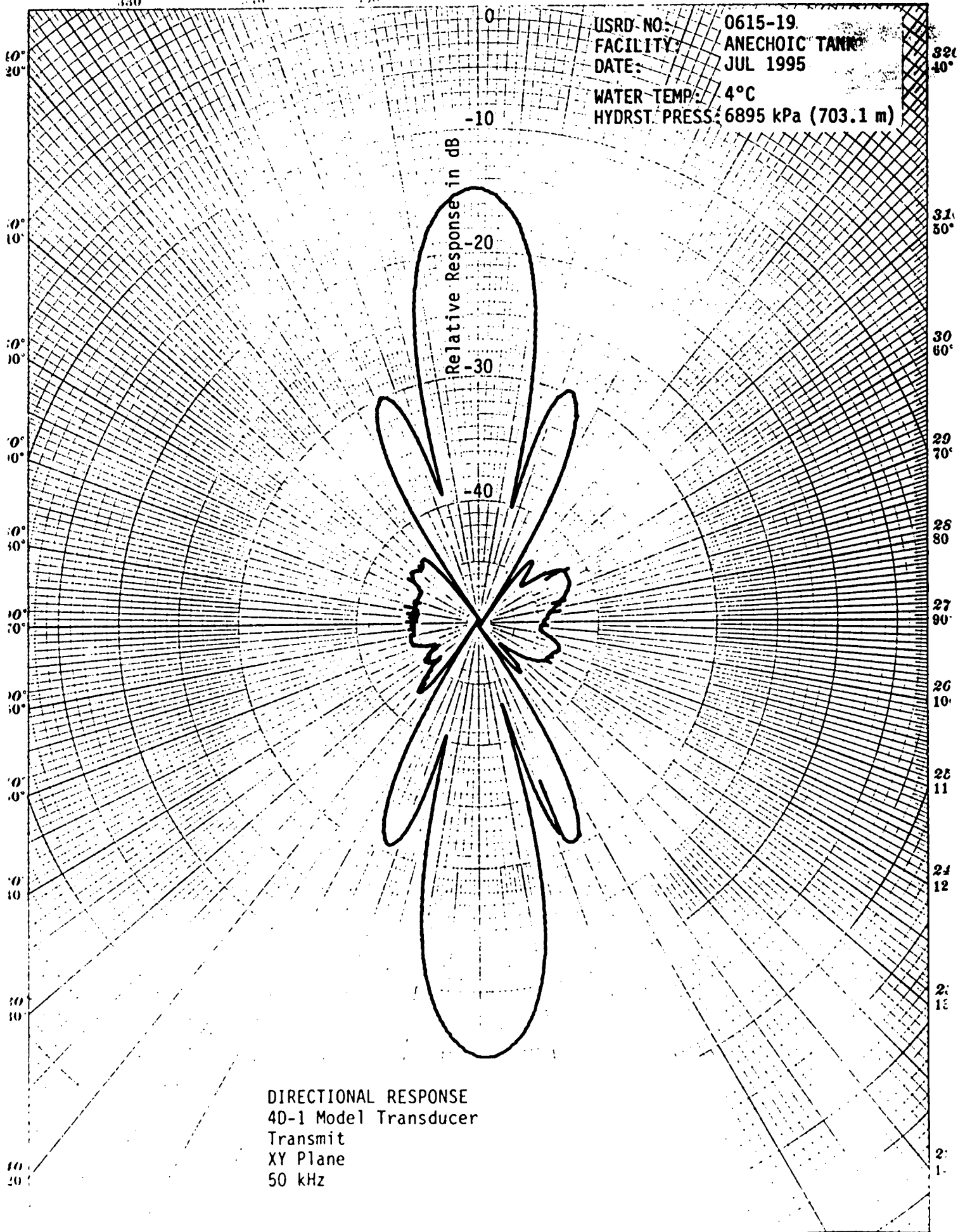
30°  
330°

10°  
340°

20°  
350°

30°  
360°

USRD NO: 0615-19  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)





330°  
330°

340°  
340°

350°  
350°

0°  
0°

10°  
10°

20°  
20°

30°  
30°

USRD NO:  
FACILITY:  
DATE:

0615-20  
ANECHOIC TANK  
JUL 1995

WATER TEMP:  
HYDRST PRESS:

4°C  
6895 kPa (703.1 m)

Relative Response in dB

0

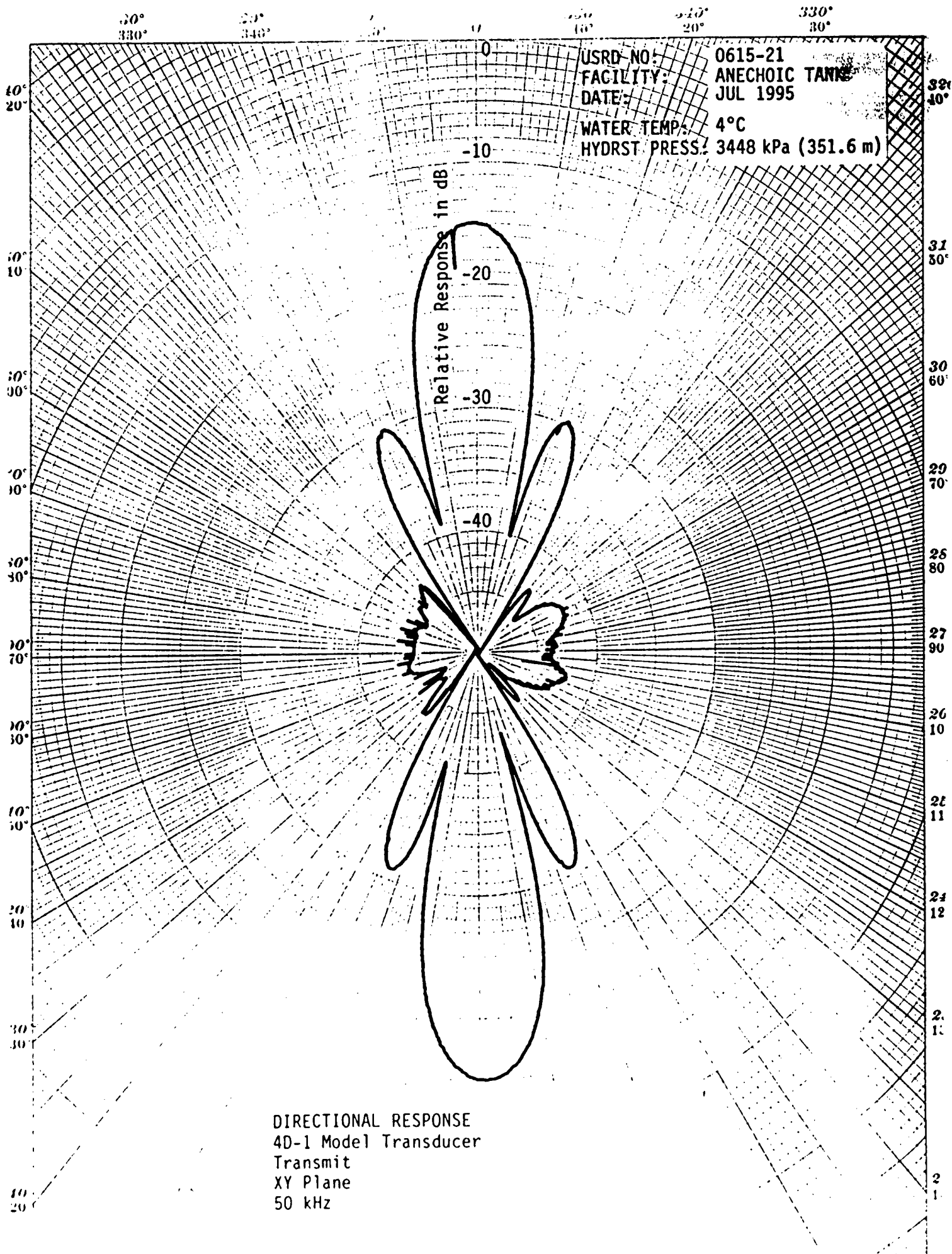
-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
65 kHz



30°  
330°

30°  
340°

30°  
350°

30°  
360°

30°  
370°

30°  
380°

30°  
390°

USRD NO: 0615-22  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

30°  
330°20°  
340°10°  
350°

0°

10°  
30°20°  
30°30°  
30°USRD NO:  
FACILITY:  
DATE:0615-23  
ANECHOIC TANK  
JUL 1995WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
50 kHz



30°  
330°

20°  
340°

10°  
350°

0°  
10°

20°  
20°

30°  
30°

USRD NO:  
FACILITY:  
DATE:

0615-24  
ANECHOIC TANK  
JUL 1995

WATER TEMP: 4°C

HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

0

-10

-20

-30

-40

32°  
40°

31°  
50°

30°  
60°

29°  
70°

28°  
80°

27°  
90°

26°  
10°

25°  
11°

24°  
12°

23°  
13°

22°  
14°

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
65 kHz

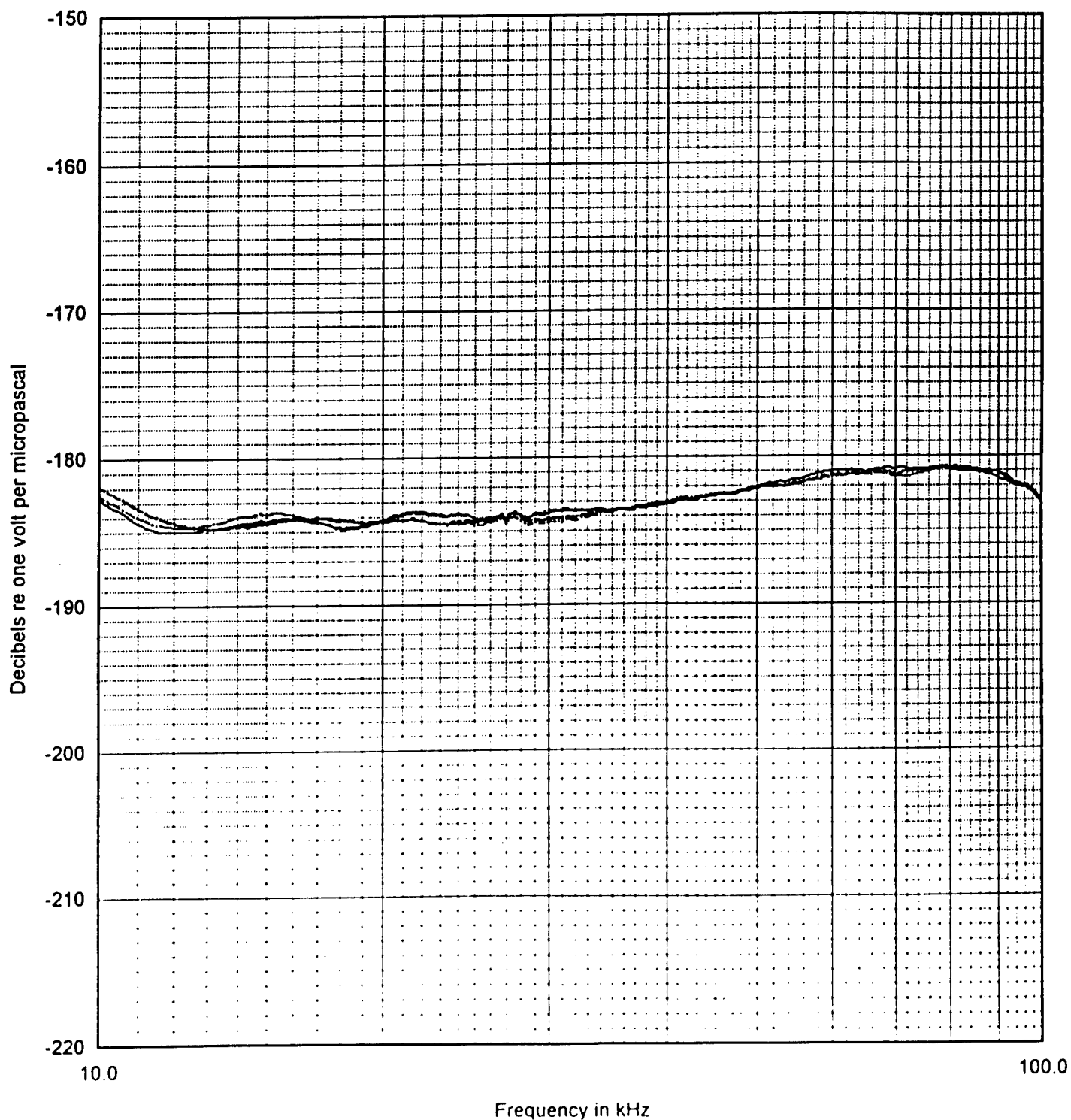
## FREE-FIELD VOLTAGE SENSITIVITY

4D-1 Model Transducer

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle



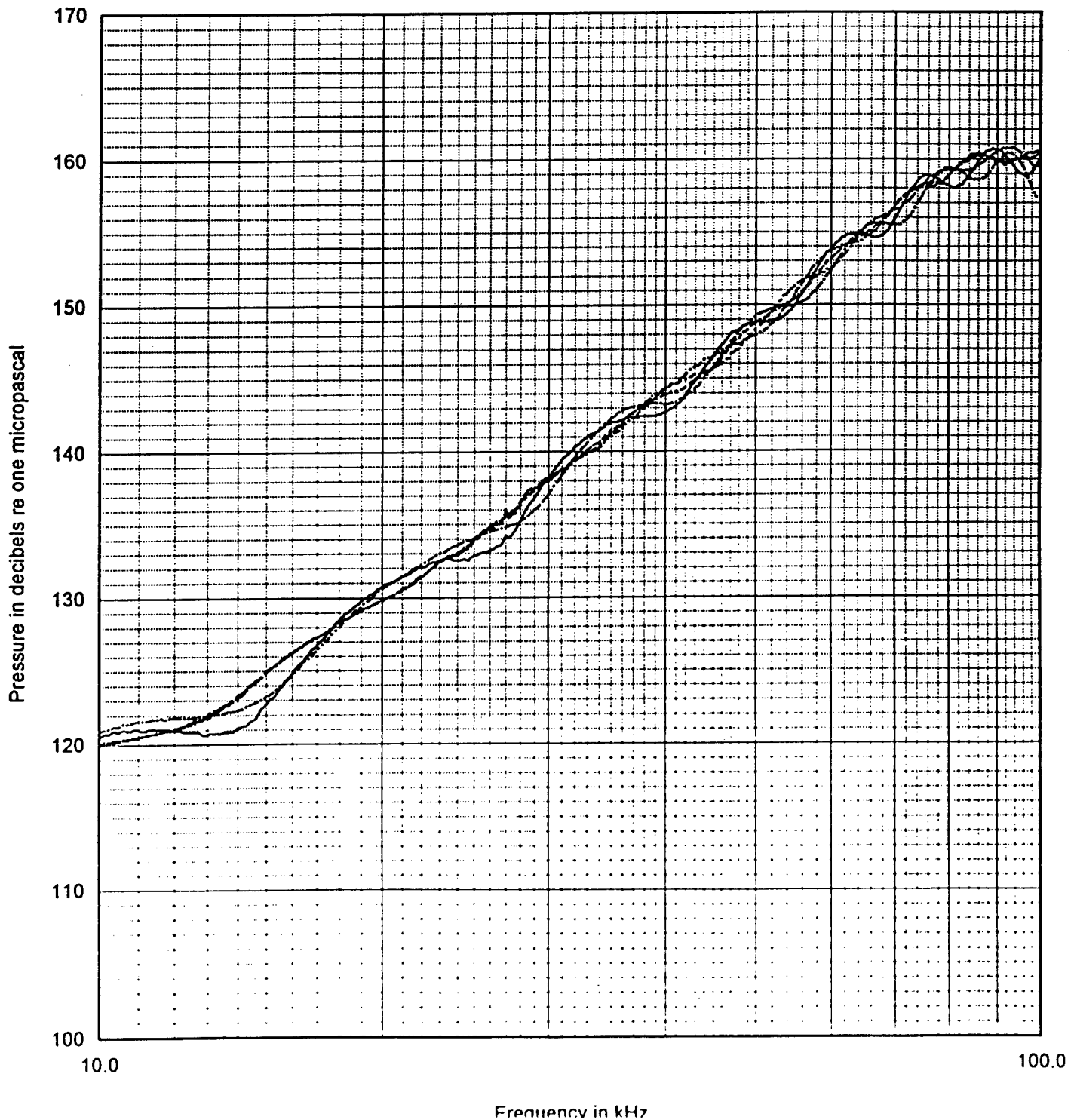
## TRANSMITTING VOLTAGE RESPONSE

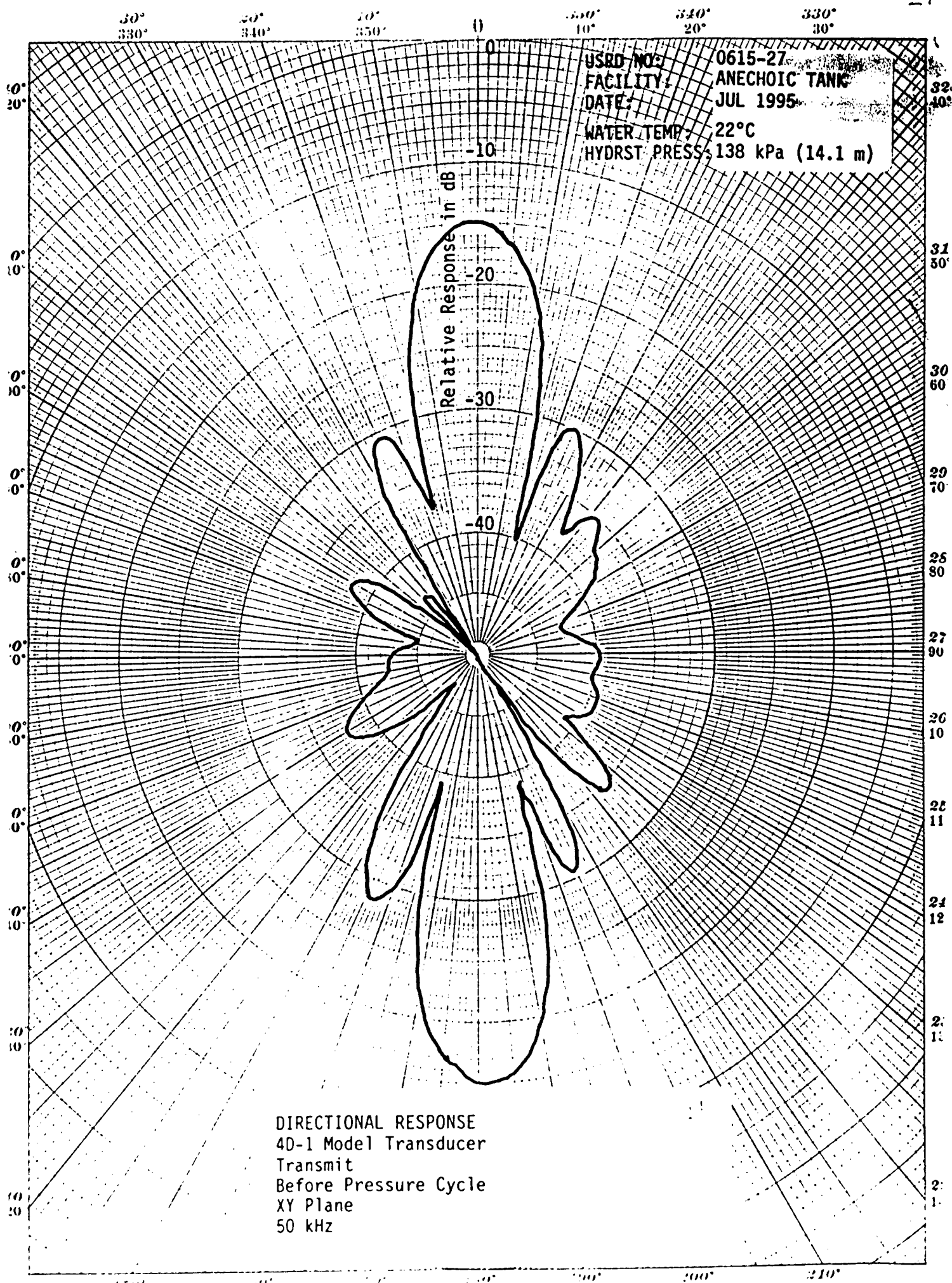
4D-1 Model Transducer

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle





30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

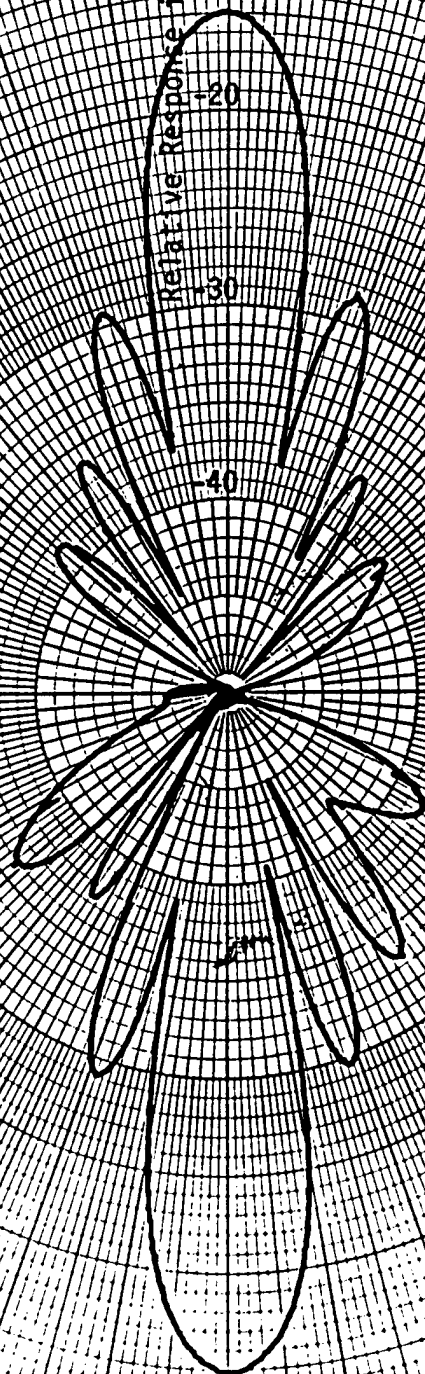
340°  
20°

330°  
30°

22

USRB NO. 0615-28  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRO PRESS: 138 kPa (14.1 m)\*

Relative Response in db



DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
65 kHz

150°  
210°

160°  
200°

170°  
190°

180°  
180°

190°  
170°

200°  
160°

210°  
150°

22°  
140°



30°  
830°

20°  
840°

10°  
850°

0

350°  
10°

340°  
20°

330°  
80°

23

USRB NO. 0615-29  
FACILITY: ANECHOIC CHAMBER  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRO PRESS: 3448 kPa (351.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
50 kHz

150°

160°

170°

180°

190°

200°

210°

330  
310  
300  
290  
280  
270  
260  
250  
240  
230  
220

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

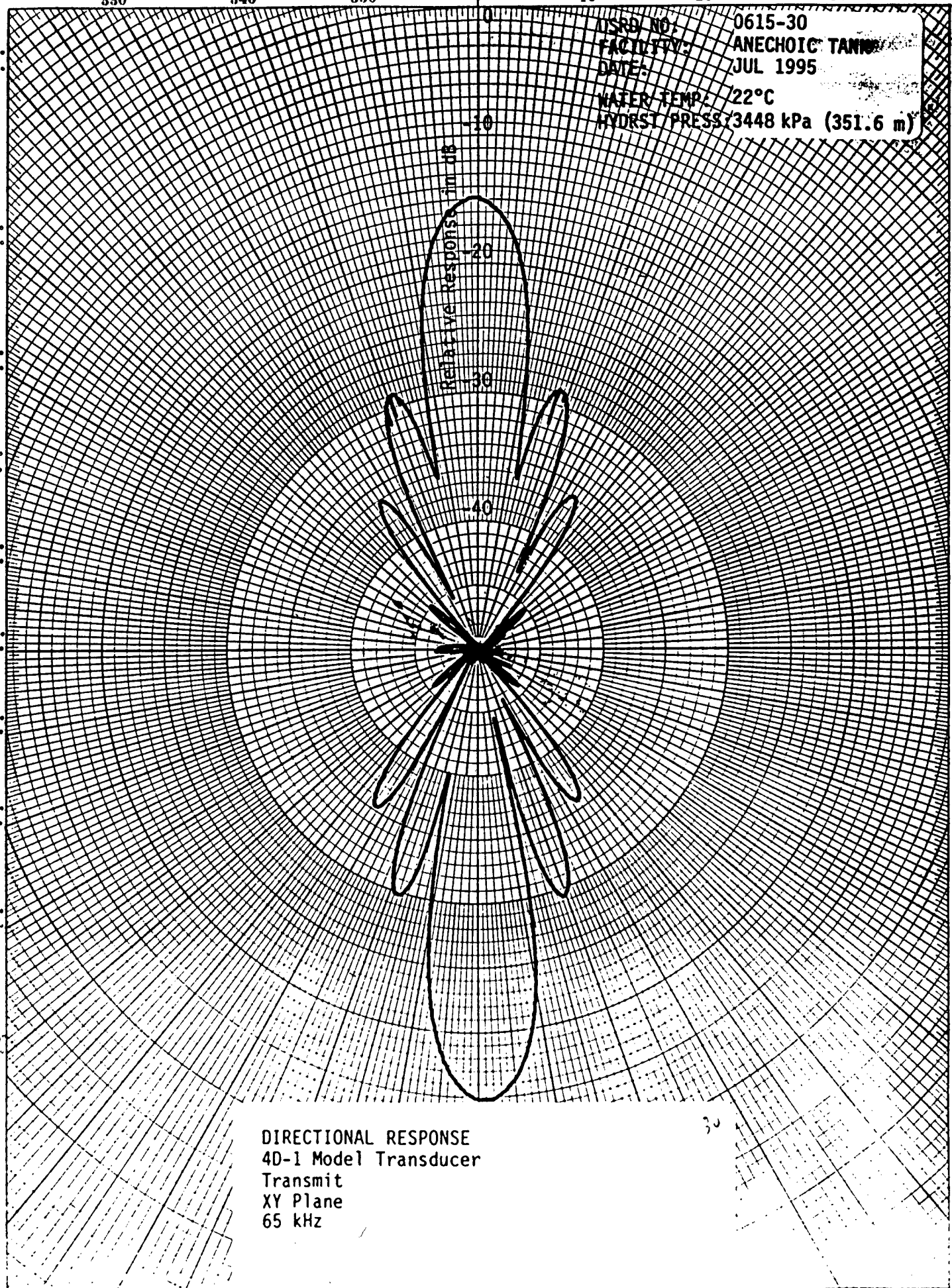
340°  
20°

330°  
30°

24

USRB NO. 0615-30  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDST PRESS: 3448 kPa (351.6 m)

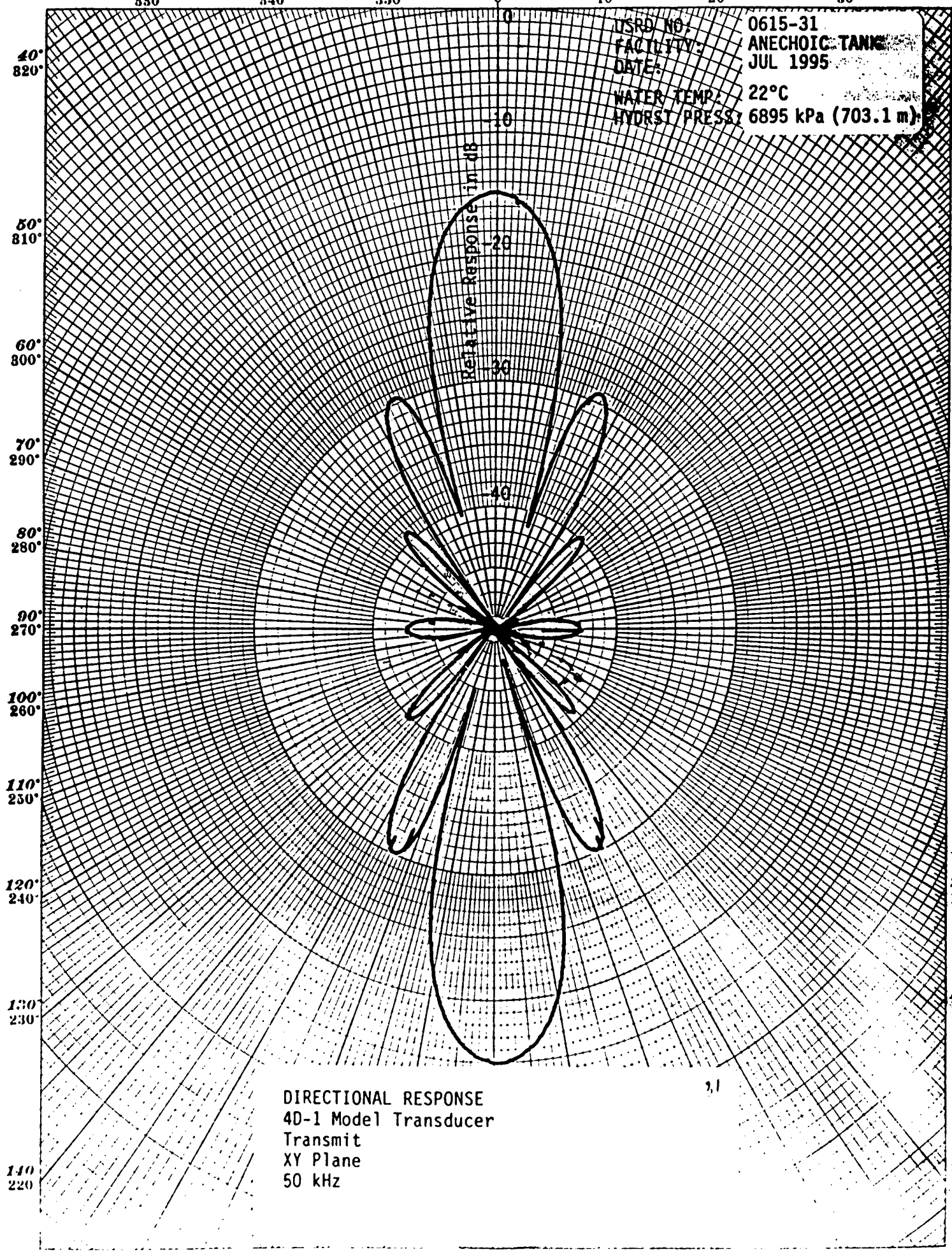
Relative Response, dB



DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

30° 20° 10° 0° 350° 340° 330°  
830° 840° 850° 10° 20° 30°

USRD NO. 0615-31  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 6895 kPa (703.1 m)



DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
50 kHz

150° 160° 170° 180° 190° 200° 210°  
160° 170° 180° 190° 200° 210°



30°  
330°

20°  
340°

10°  
350°

0°

35°  
10°

340°  
20°

330°  
30°

26

USRD NO. 0615-32  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDST PRESS: 6895 kPa (703.1 m)

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

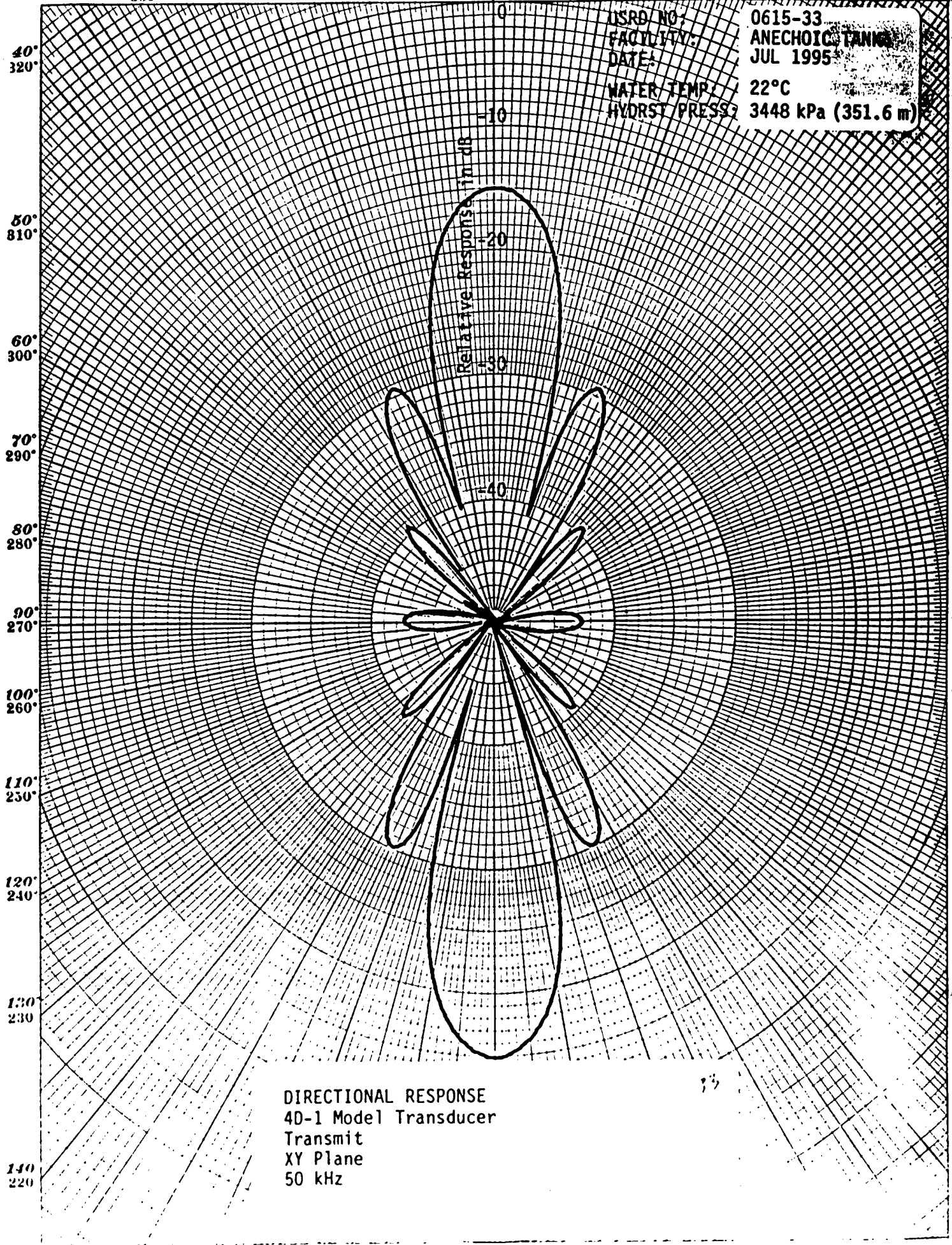
140°  
220°

Relative Response in dB

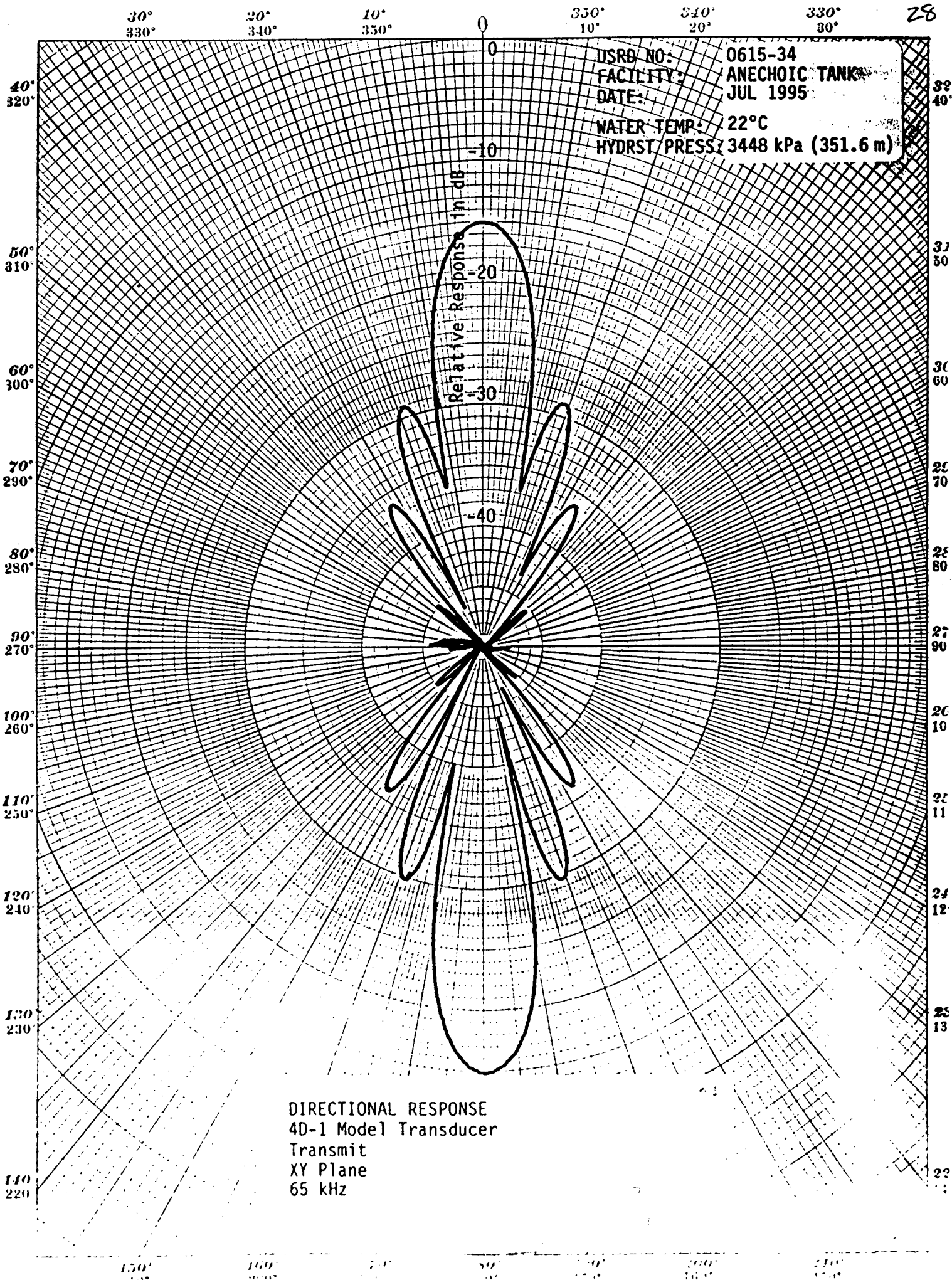
DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

30° 20° 10° 0 350° 340° 330° 27

USRD NO: 0615-33  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 3448 kPa (351.6 m)



DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
XY Plane  
50 kHz



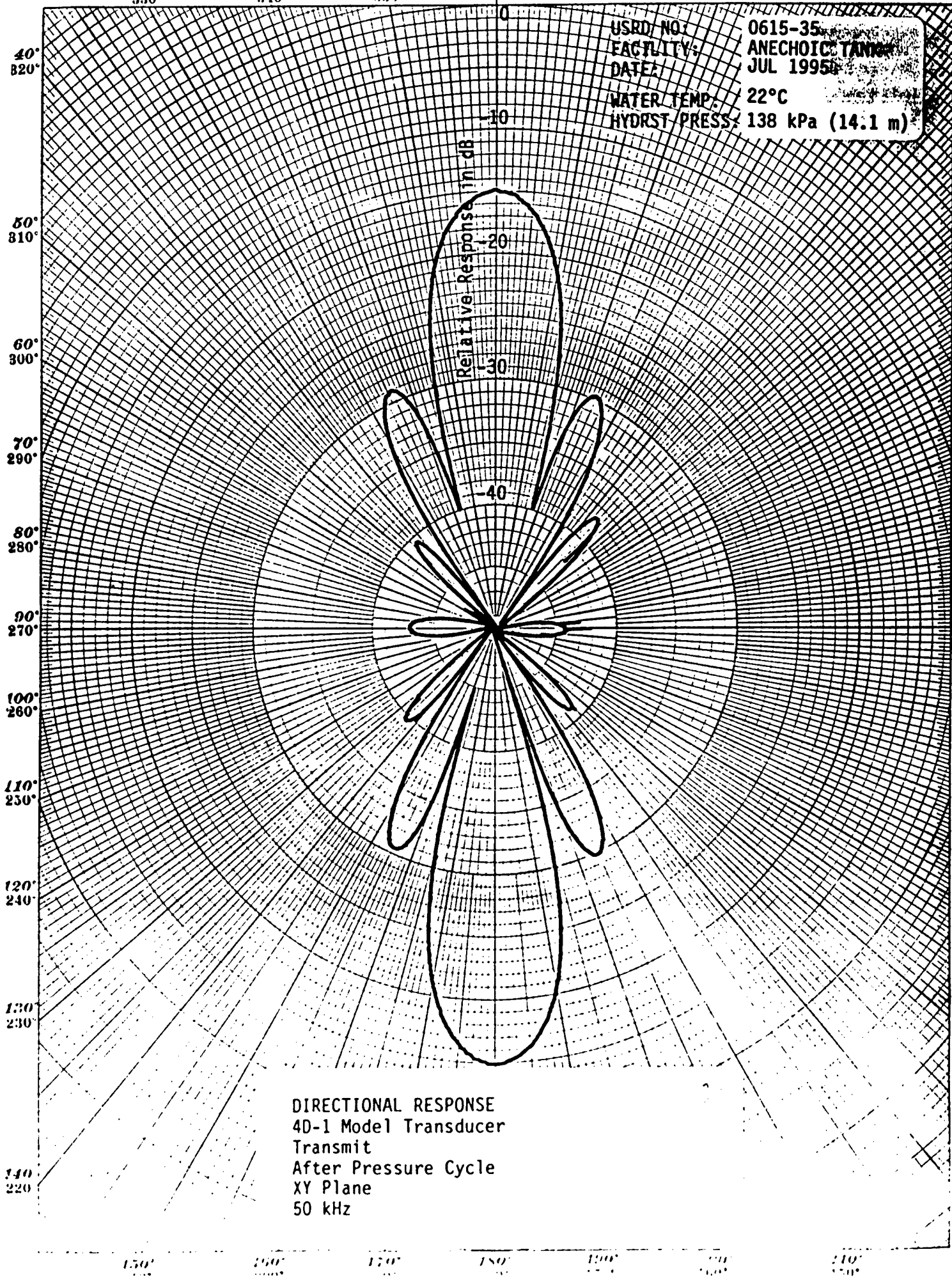
30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

29

USRD NO: 0615-35  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 138 kPa (14.1 m)

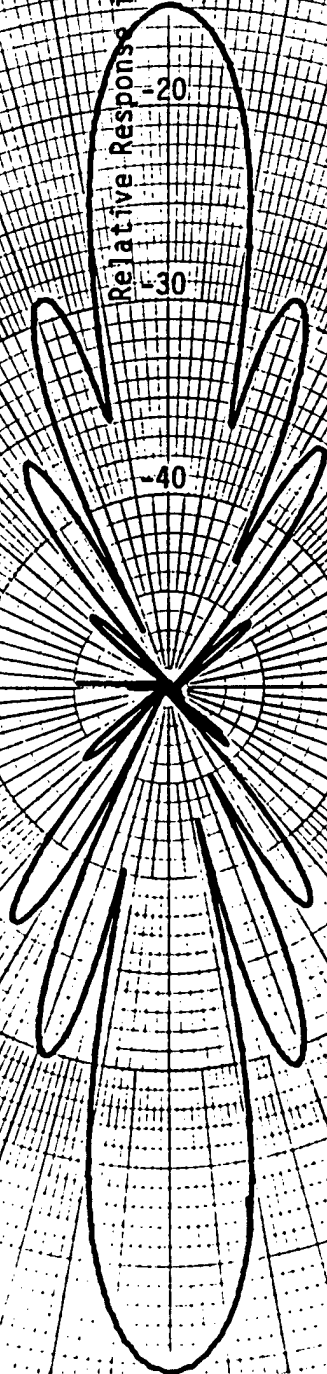




30° 330° 20° 340° 10° 350° 0 250° 10° 340° 20° 330° 30°

USRD NO: 0615-36  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB



DIRECTIONAL RESPONSE  
4D-1 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
65 kHz

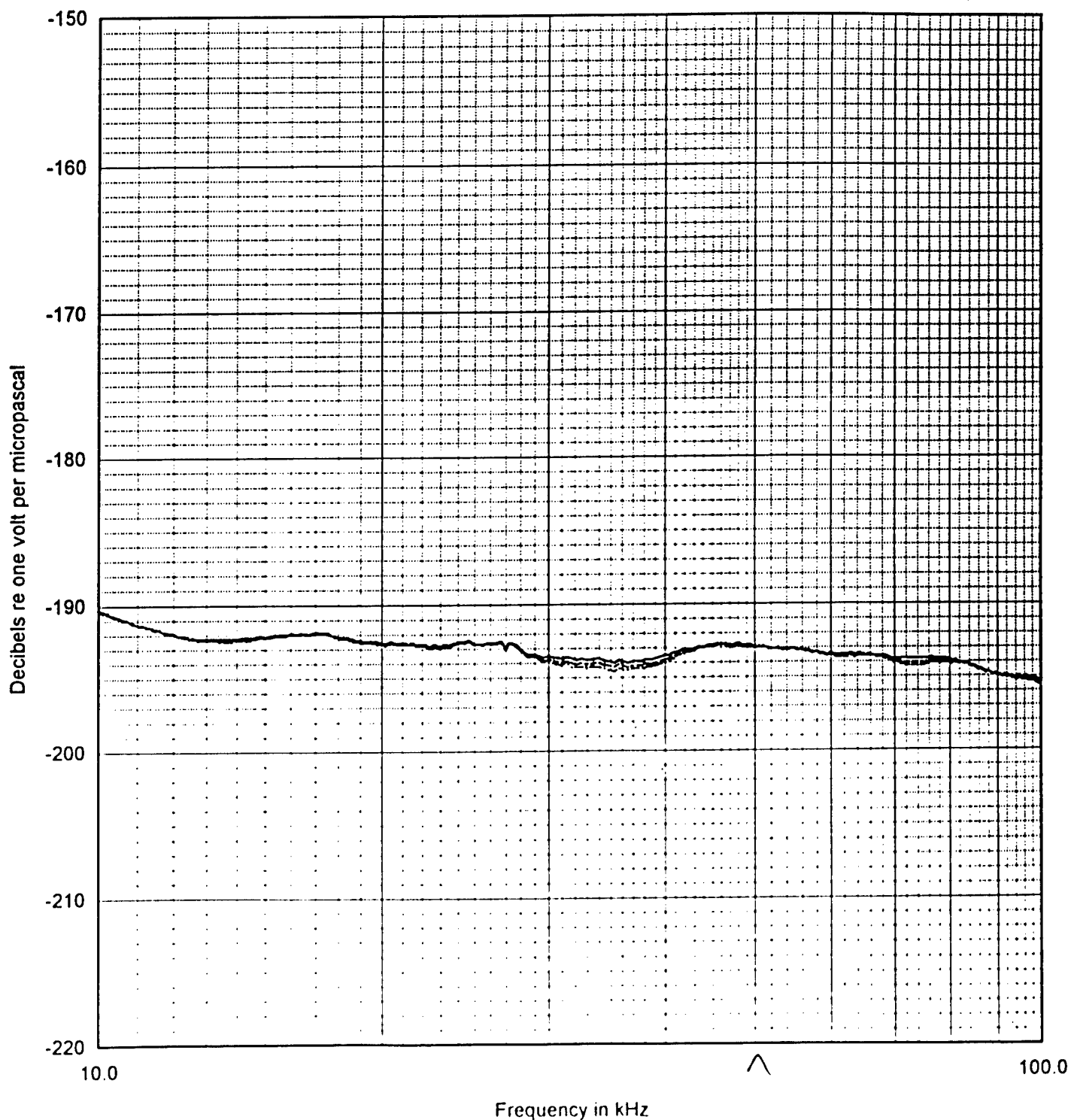
## FREE-FIELD VOLTAGE SENSITIVITY

4H-1 Model Transducer

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
- - - - - 6895 kPa ( 703.1 m)  
- - - - - 3448 kPa ( 351.6 m)  
- - - - - 138 kPa ( 14.1 m) After Pressure Cycle



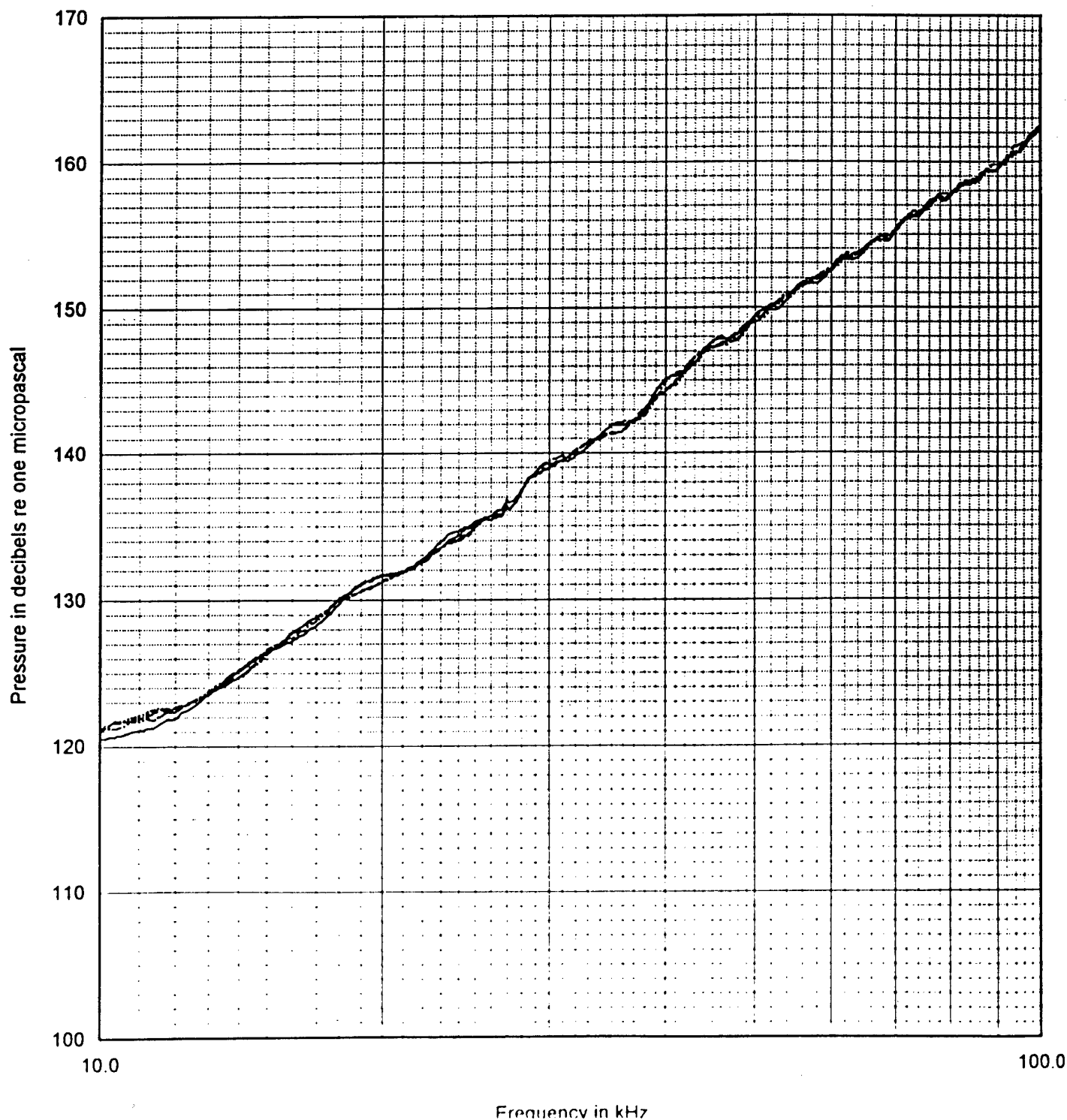
## TRANSMITTING VOLTAGE RESPONSE

4H-1 Model Transducer

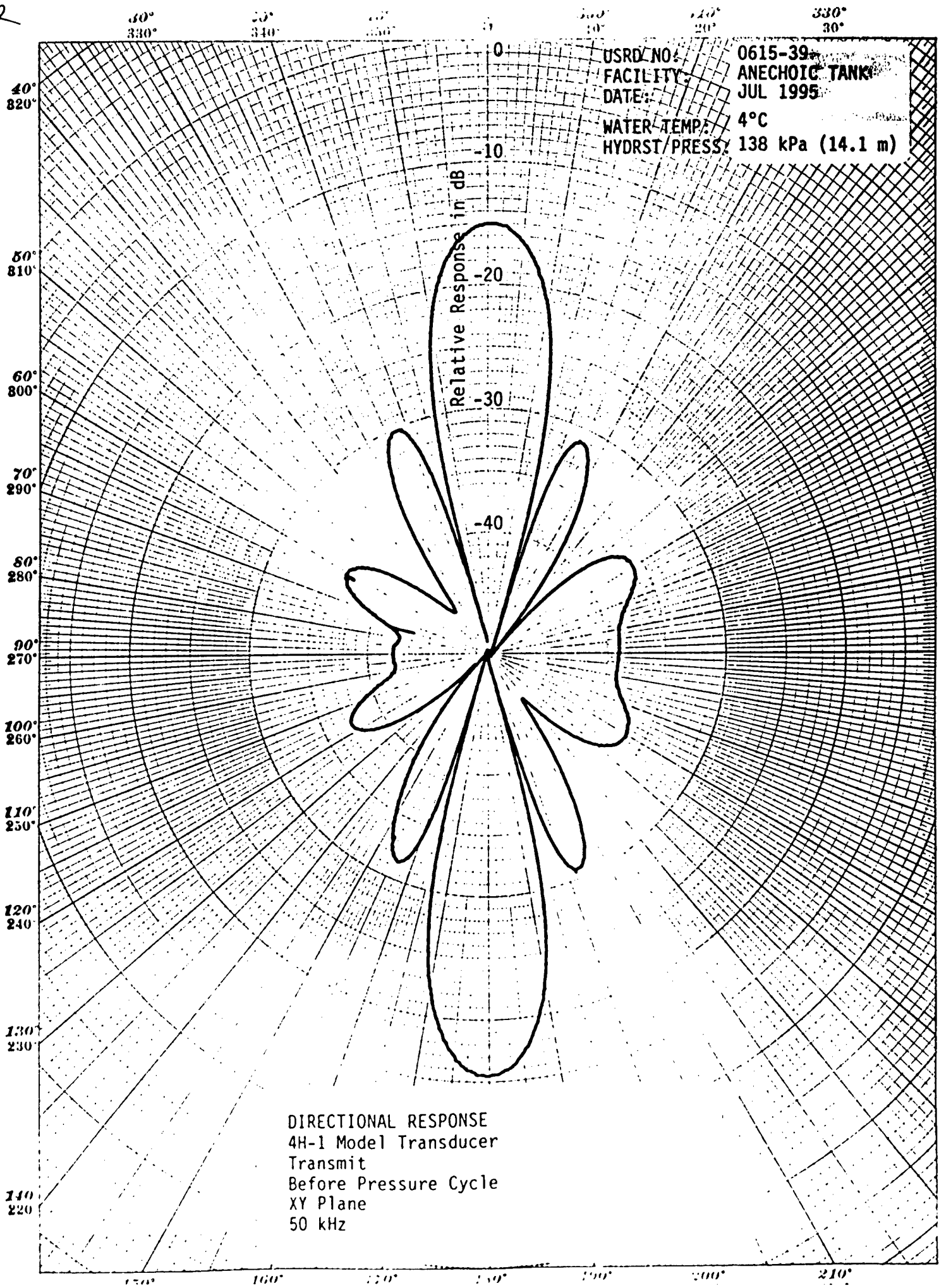
Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 3448 kPa ( 351.6 m)  
- - - - - 138 kPa ( 14.1 m) After Pressure Cycle



2



USRD NO: 0615-39  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST/PRESS: 138 kPa (14.1 m)

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
50 kHz



30°  
330°

60°  
300°

90°  
270°

120°  
240°

150°  
210°

180°  
180°

210°  
150°

3  
4

5  
6

7  
8

9  
10

11  
12

13  
14

15  
16

17  
18

19  
20

21  
22

23  
24

25  
26

27  
28

29  
30

USRD NO: 0615-40  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST/PRESS: 138 kPa (14.1 m)

Relative Response in dB  
-10  
-20  
-30  
-40

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
65 kHz

170°

160°

150°

140°

130°

120°

110°

140°  
220°

130°  
230°

120°  
240°

110°  
250°

100°  
260°

90°  
270°

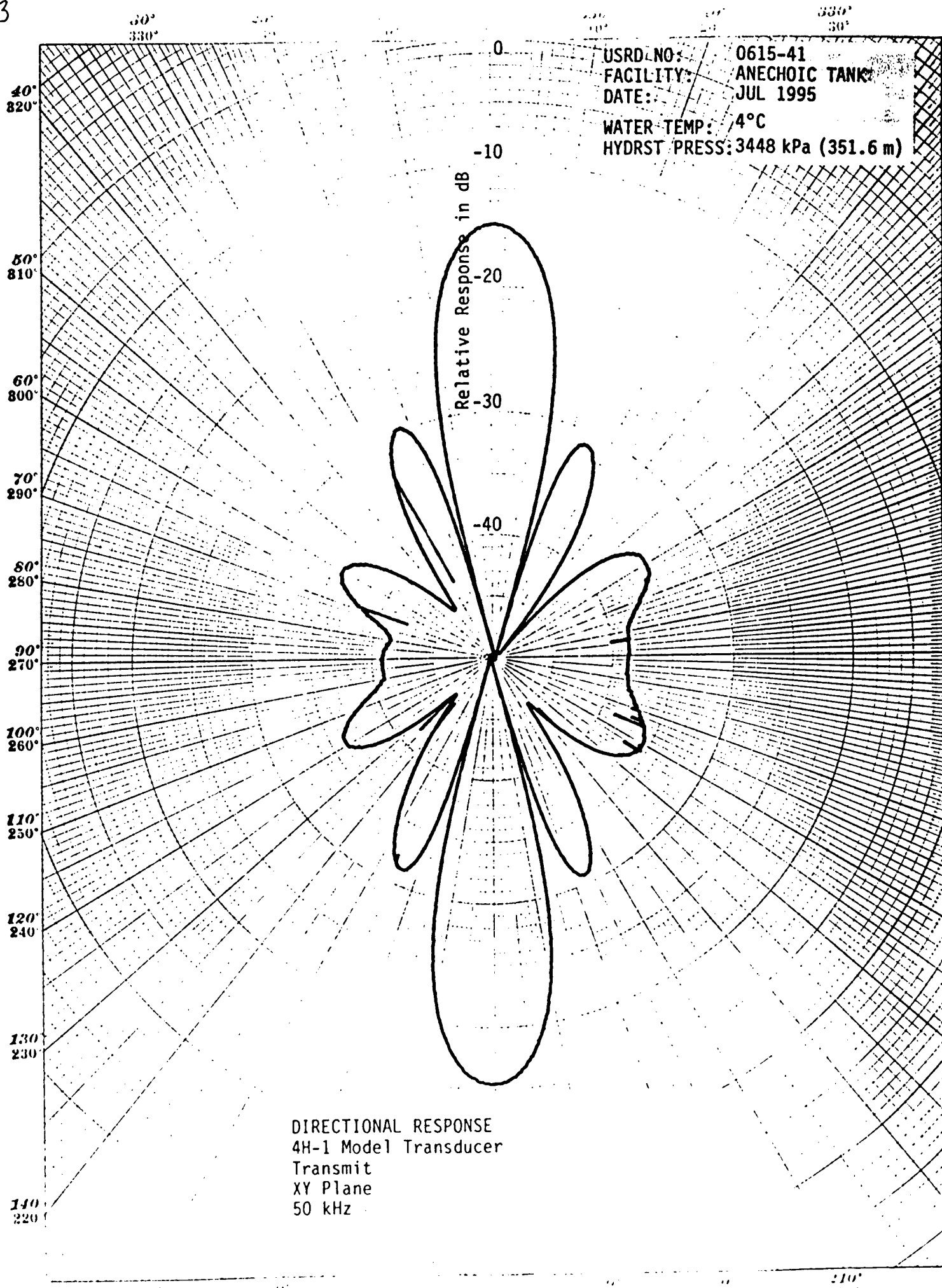
80°  
280°

70°  
290°

60°  
300°

50°  
310°

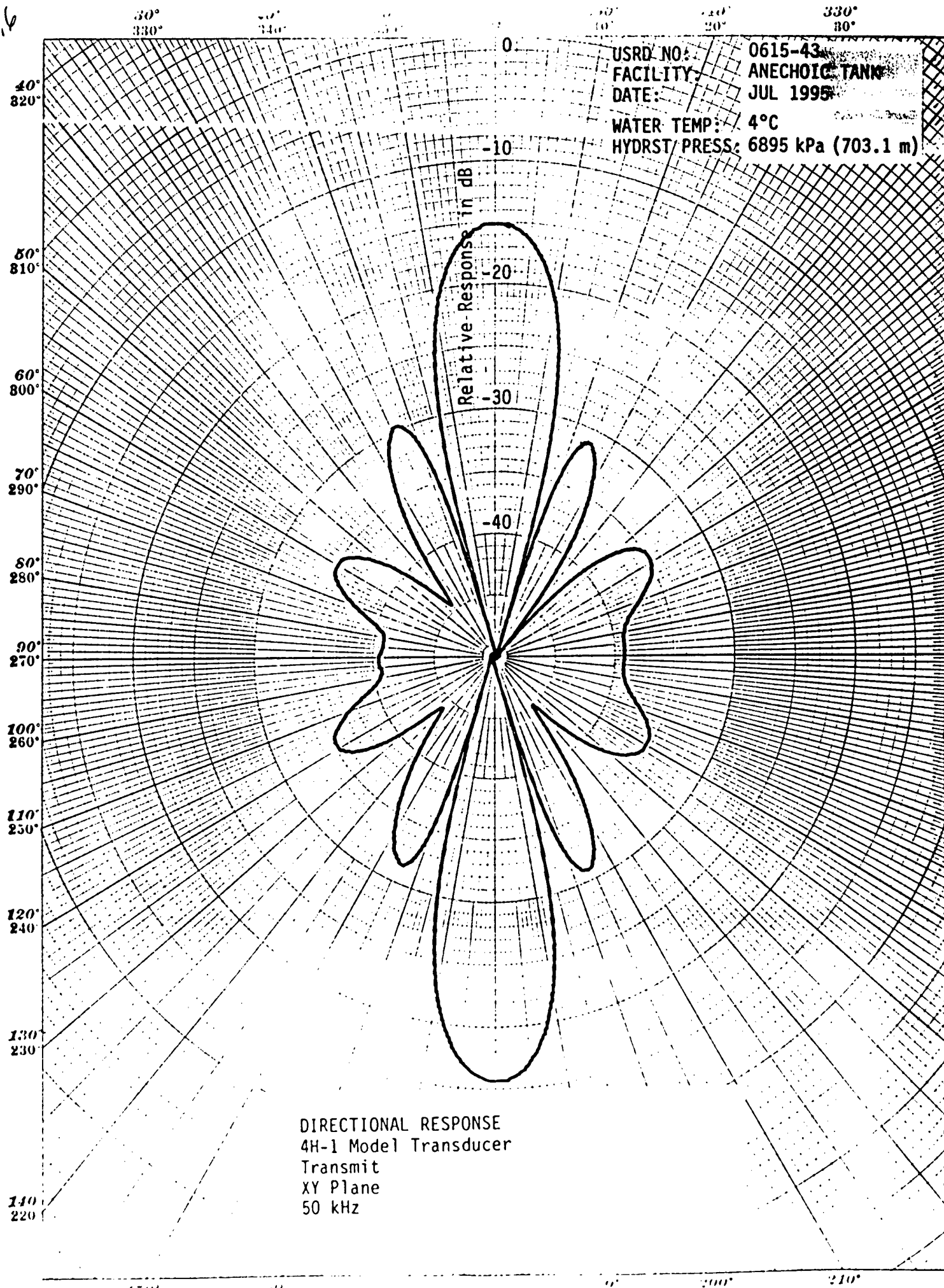
40°  
320°



USRD NO.: 0615-42  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST/ PRESS: 3448 kPa (351.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

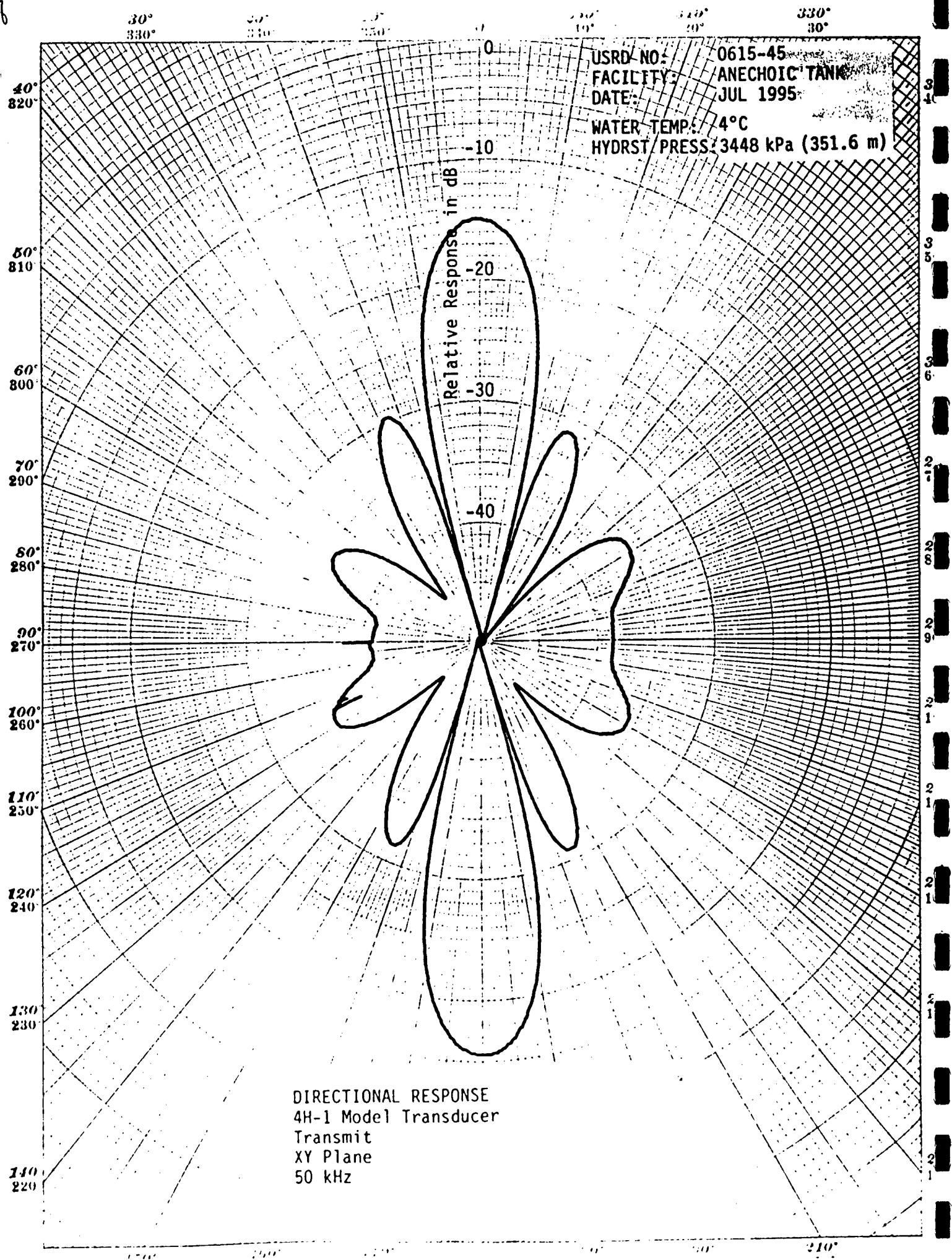


330°  
30°

~~Relative Response in dB~~

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

7





30°  
330°

60°  
340°

90°  
350°

120°  
0°

150°  
10°

180°  
20°

210°  
30°

40°  
820°

50°  
810°

60°  
800°

70°  
790°

80°  
780°

90°  
770°

100°  
760°

110°  
750°

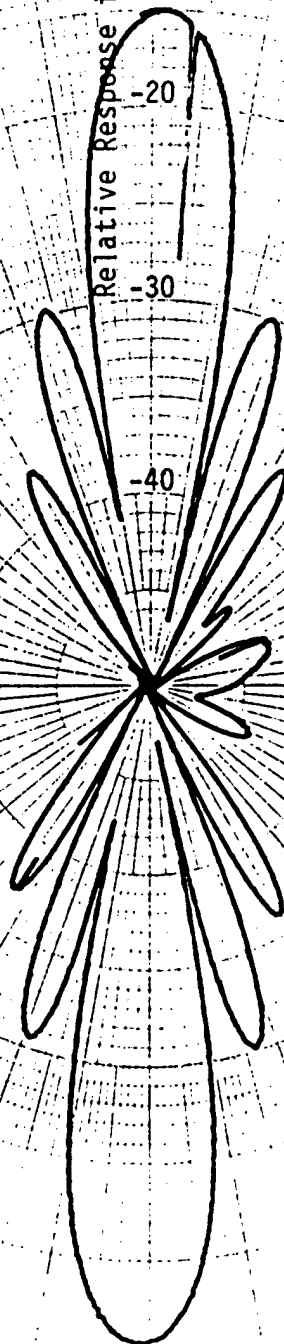
120°  
740°

130°  
730°

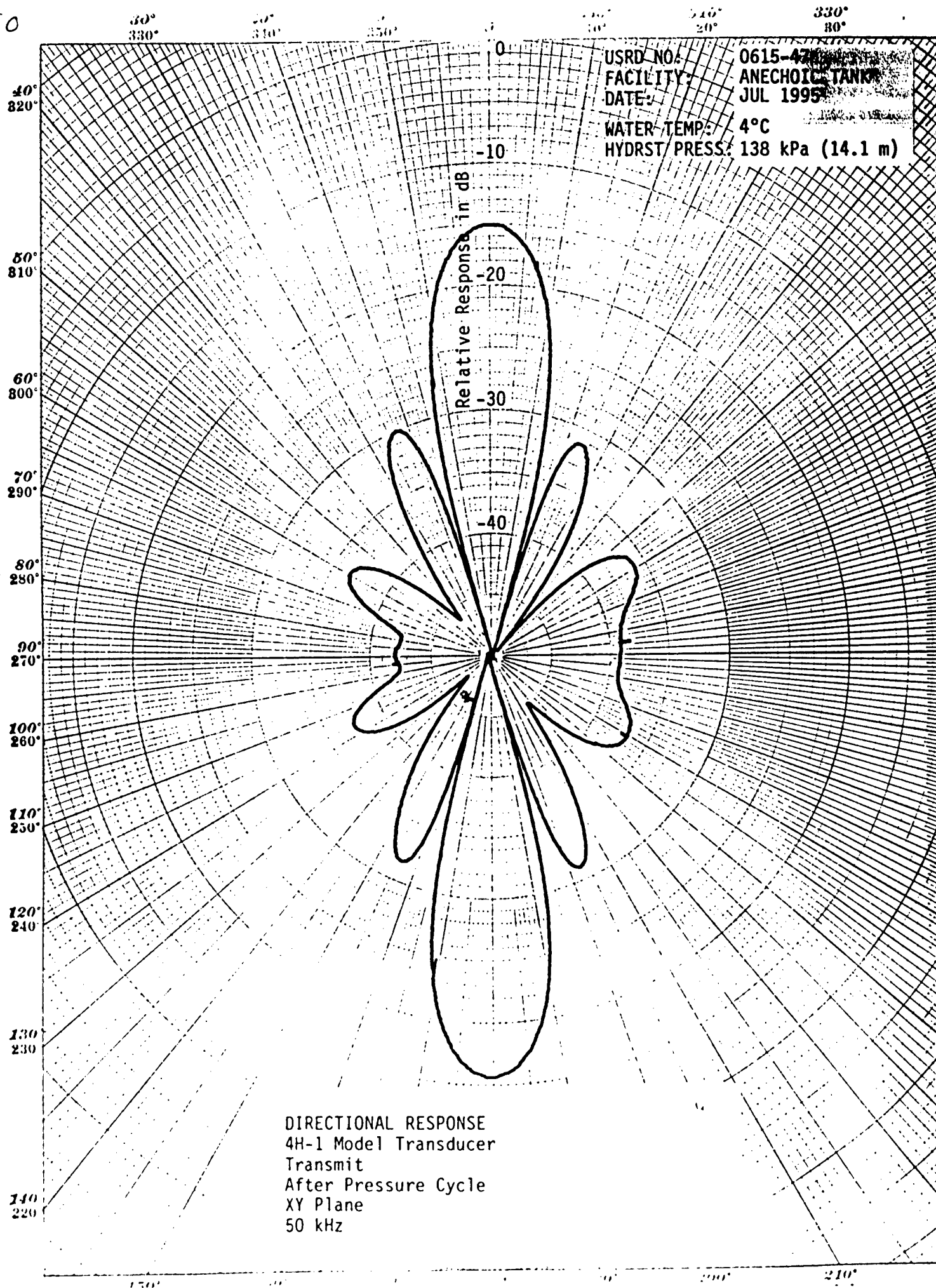
140°  
720°

USRD NO: 0615-46  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST/PRESS: 3448 kPa (351.6 m)

Relative Response in dB



DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

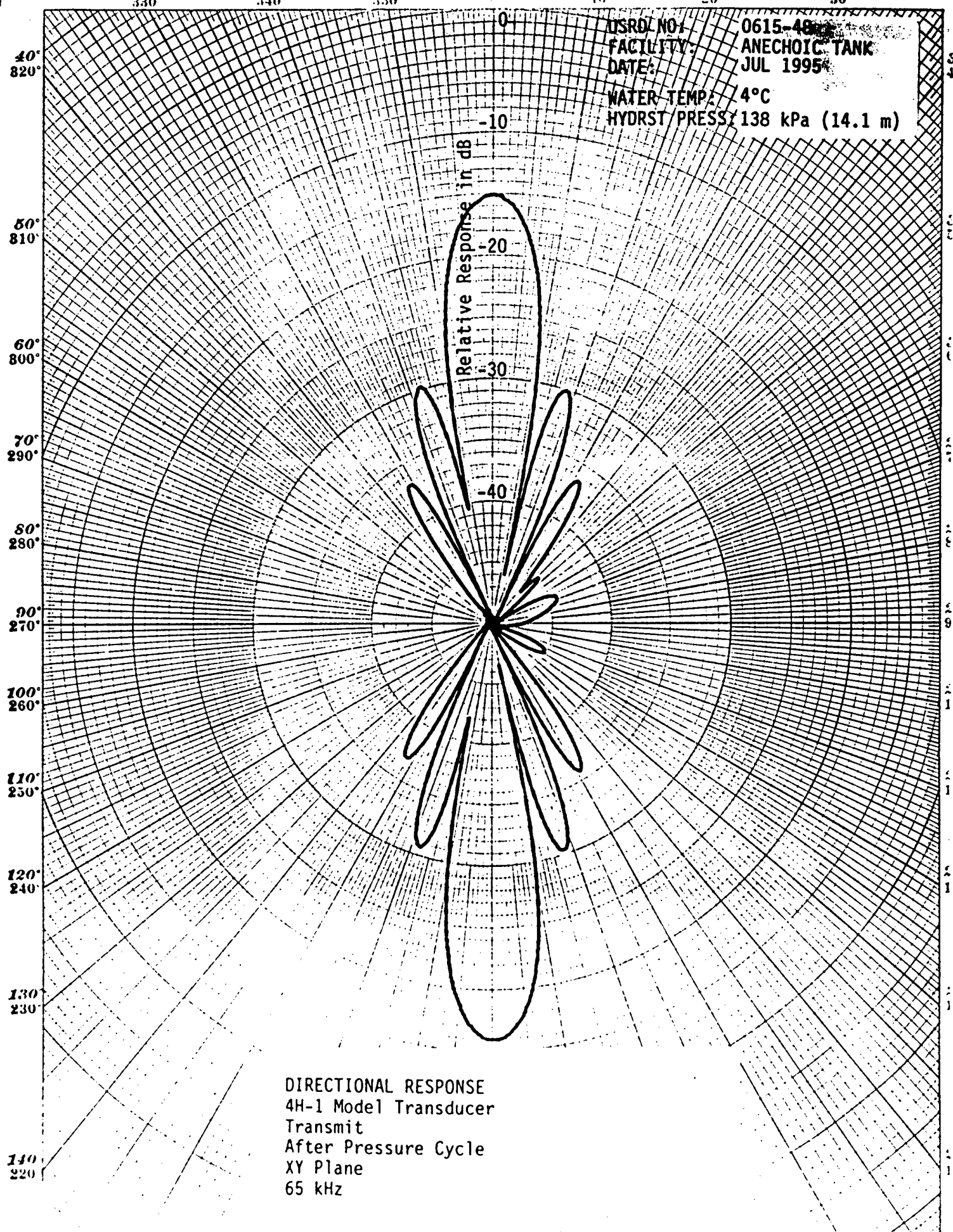




9.

30° 330° 60° 340° 90° 350° 120° 360° 150° 10° 180° 20° 210° 30° 330°

USRD NO: 0615-48  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST/PRESS: 138 kPa (14.1 m)



DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
65 kHz

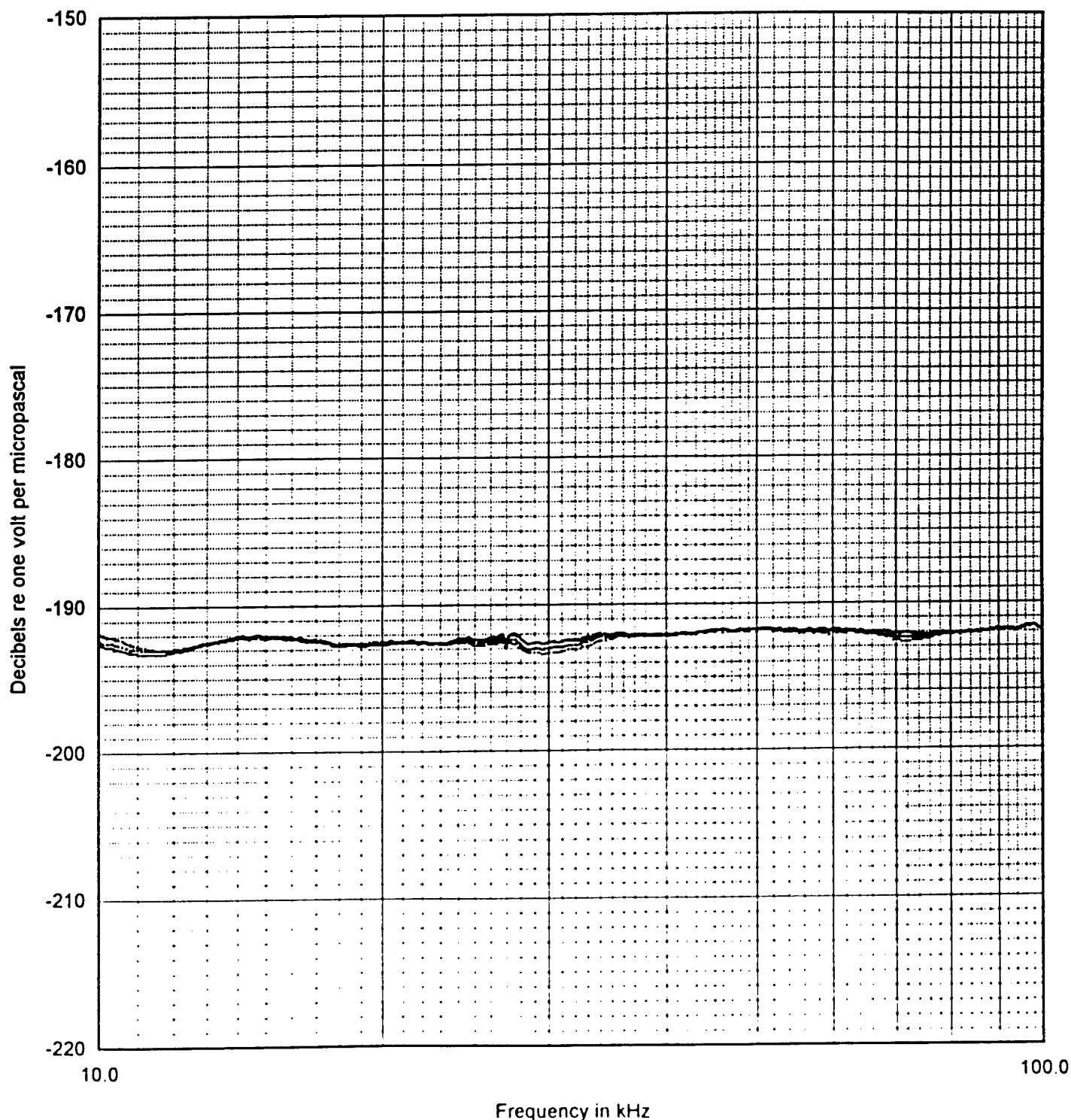
## FREE-FIELD VOLTAGE SENSITIVITY

4H-1 Model Transducer

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle



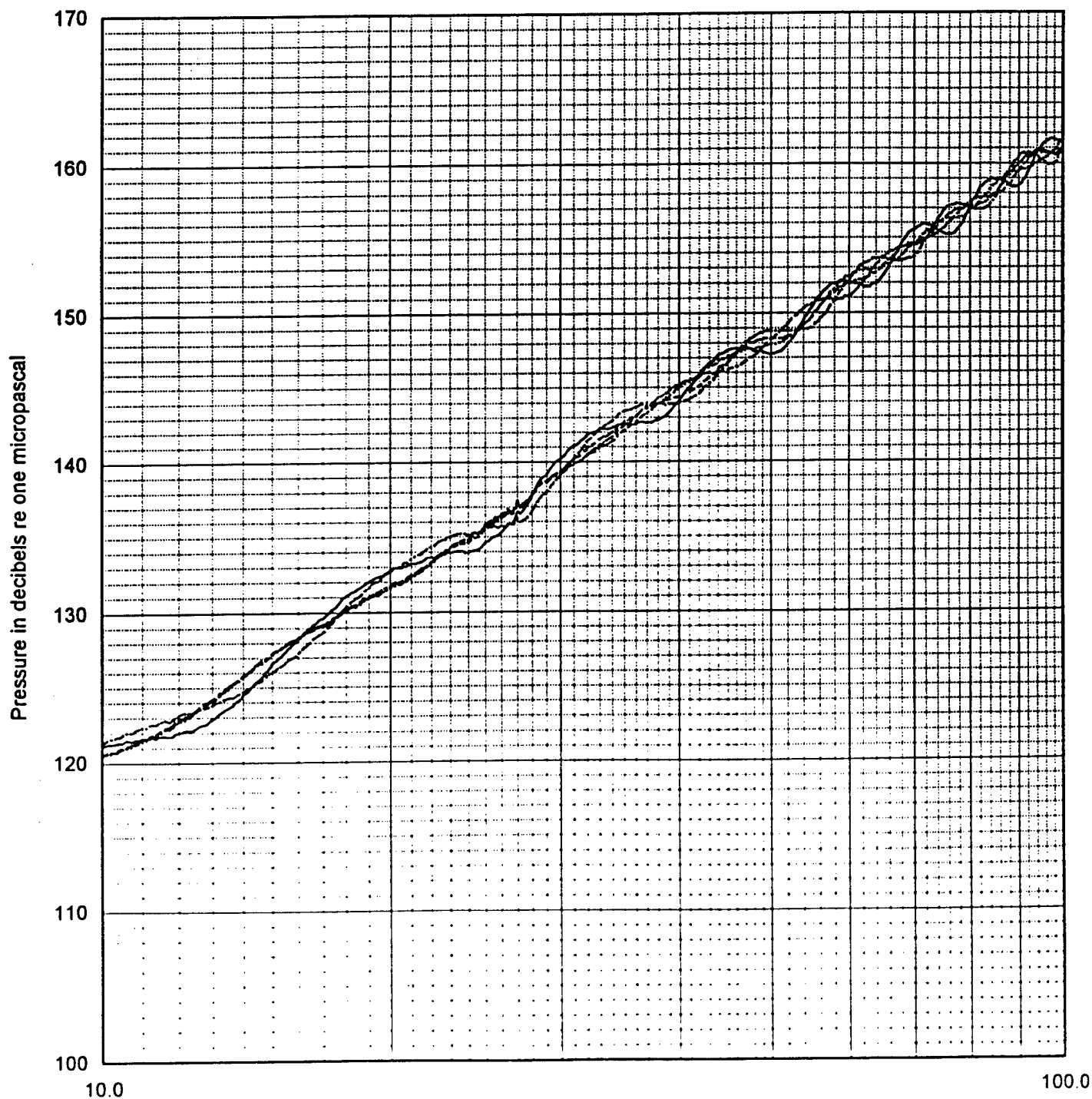
## TRANSMITTING VOLTAGE RESPONSE

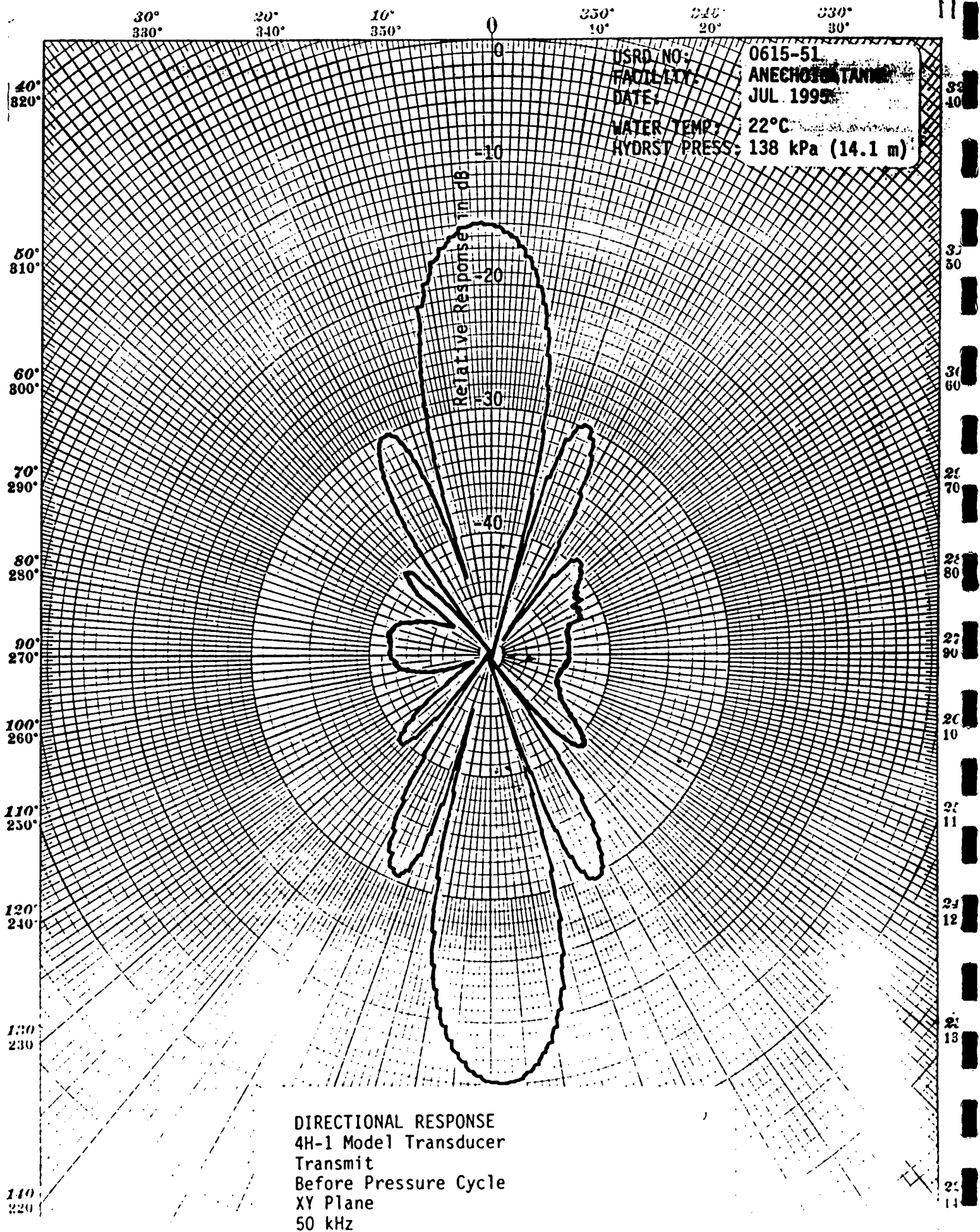
4H-1 Model Transducer

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle





30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

12

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

32  
40

33  
50

34  
60

35  
70

36  
80

37  
90

38  
10

39  
11

40  
12

41  
13

42  
14

USRD NO: 0615-52  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

-10

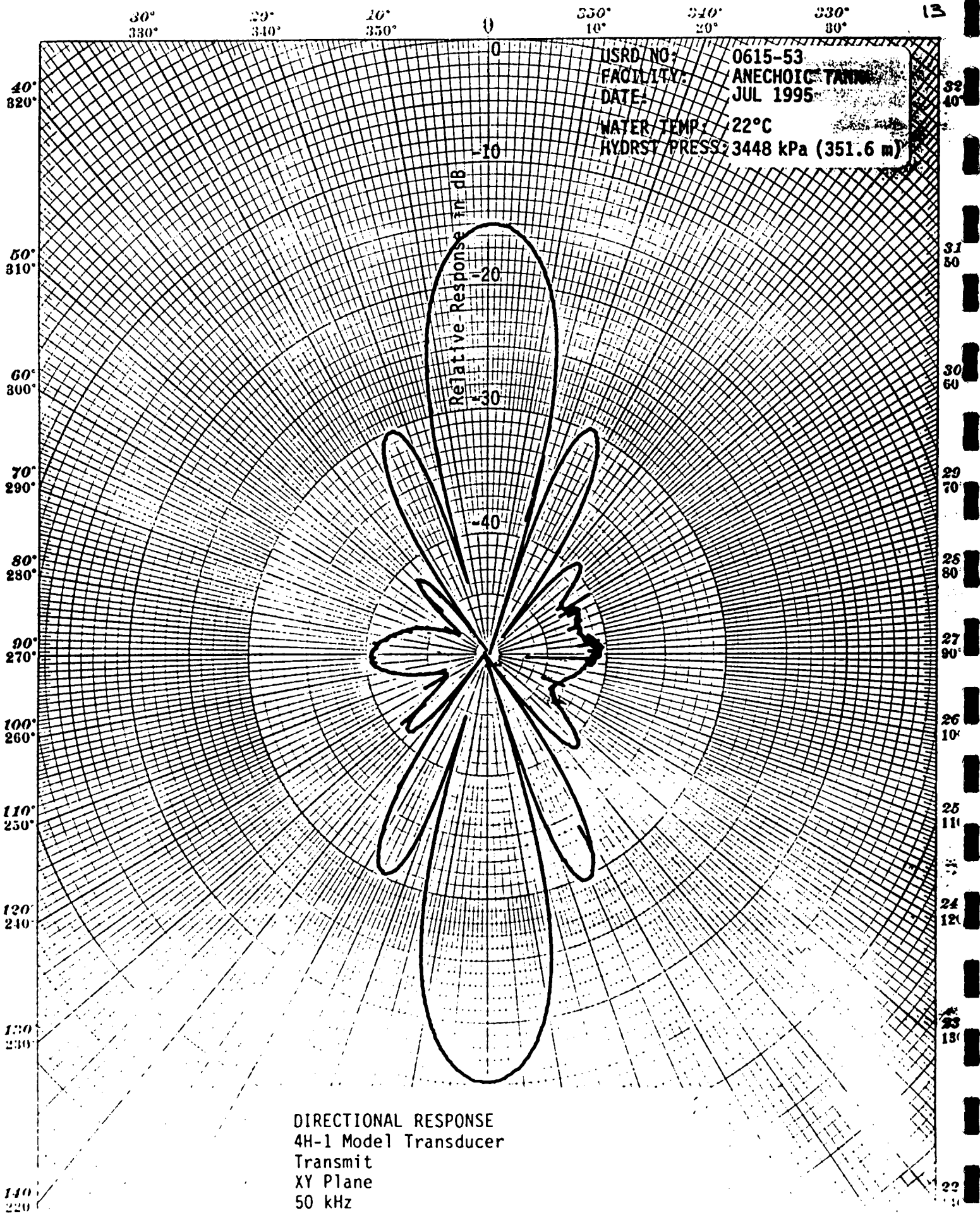
-20

-30

-40

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
65 kHz





30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

14

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

32°  
40°

33°  
50°

34°  
60°

35°  
70°

36°  
80°

37°  
90°

38°  
10°

39°  
11°

40°  
12°

41°  
13°

42°  
14°

USRD NO: 0615-54  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

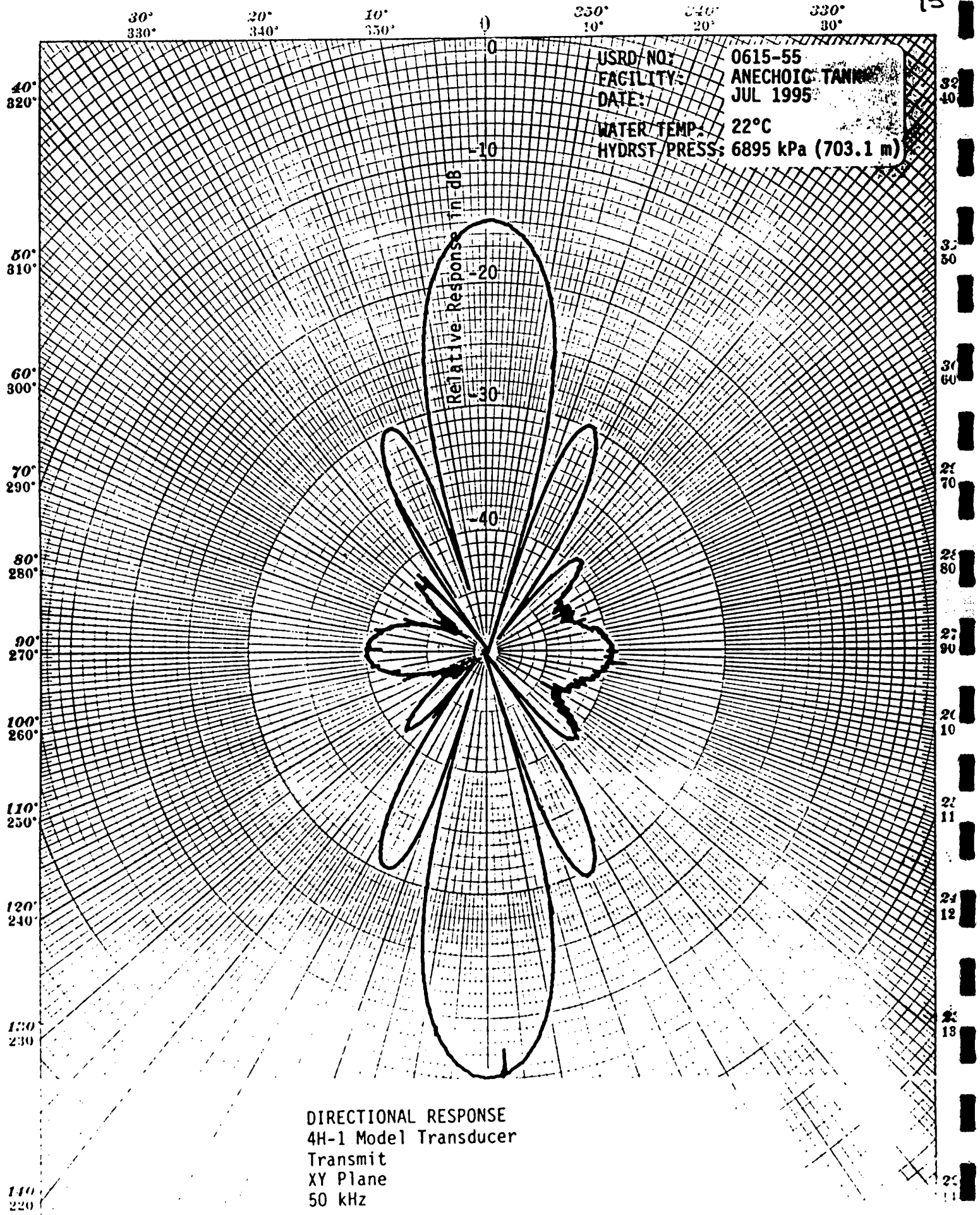
-10

-20

-30

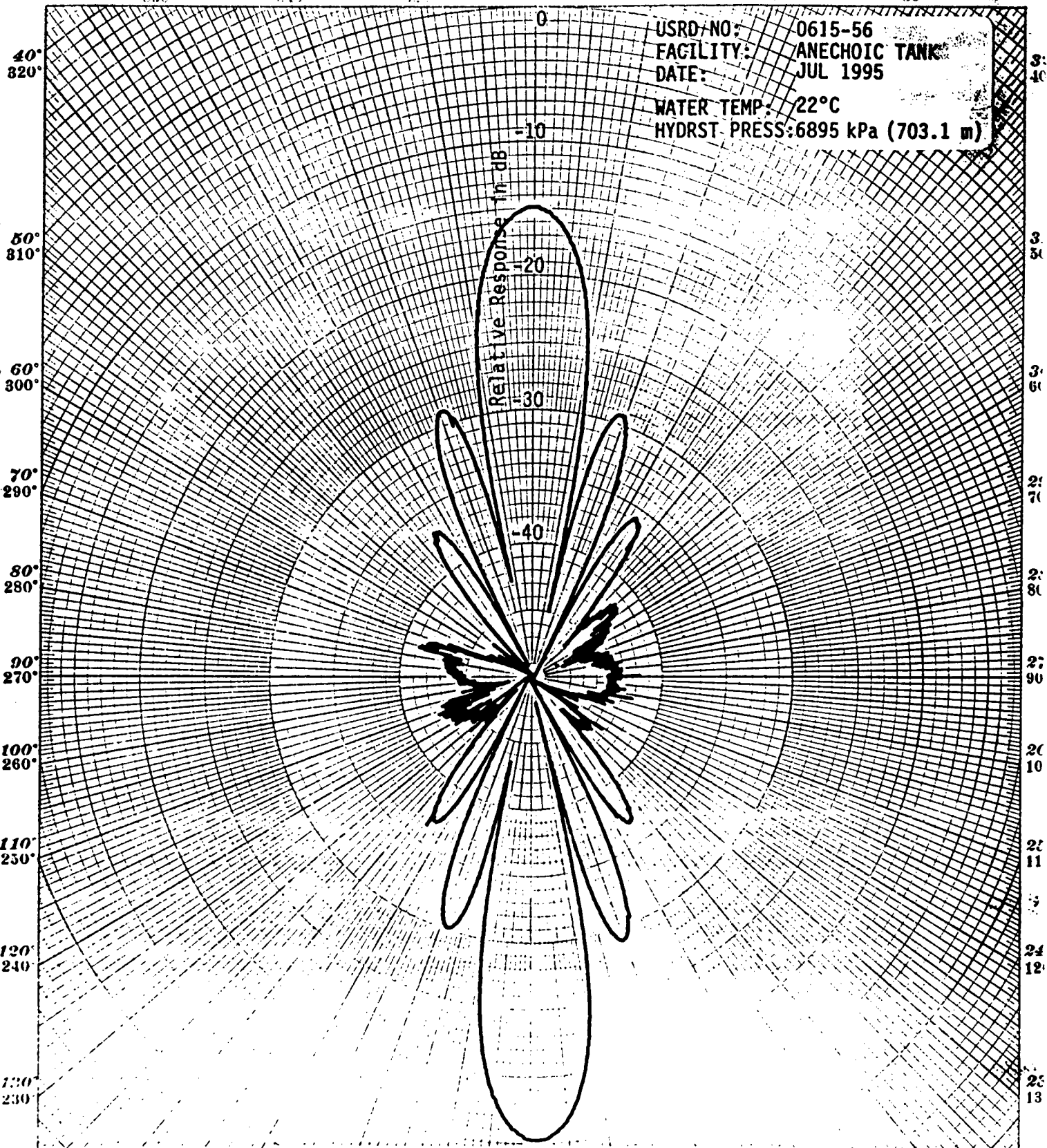
-40

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
XY Plane  
65 kHz

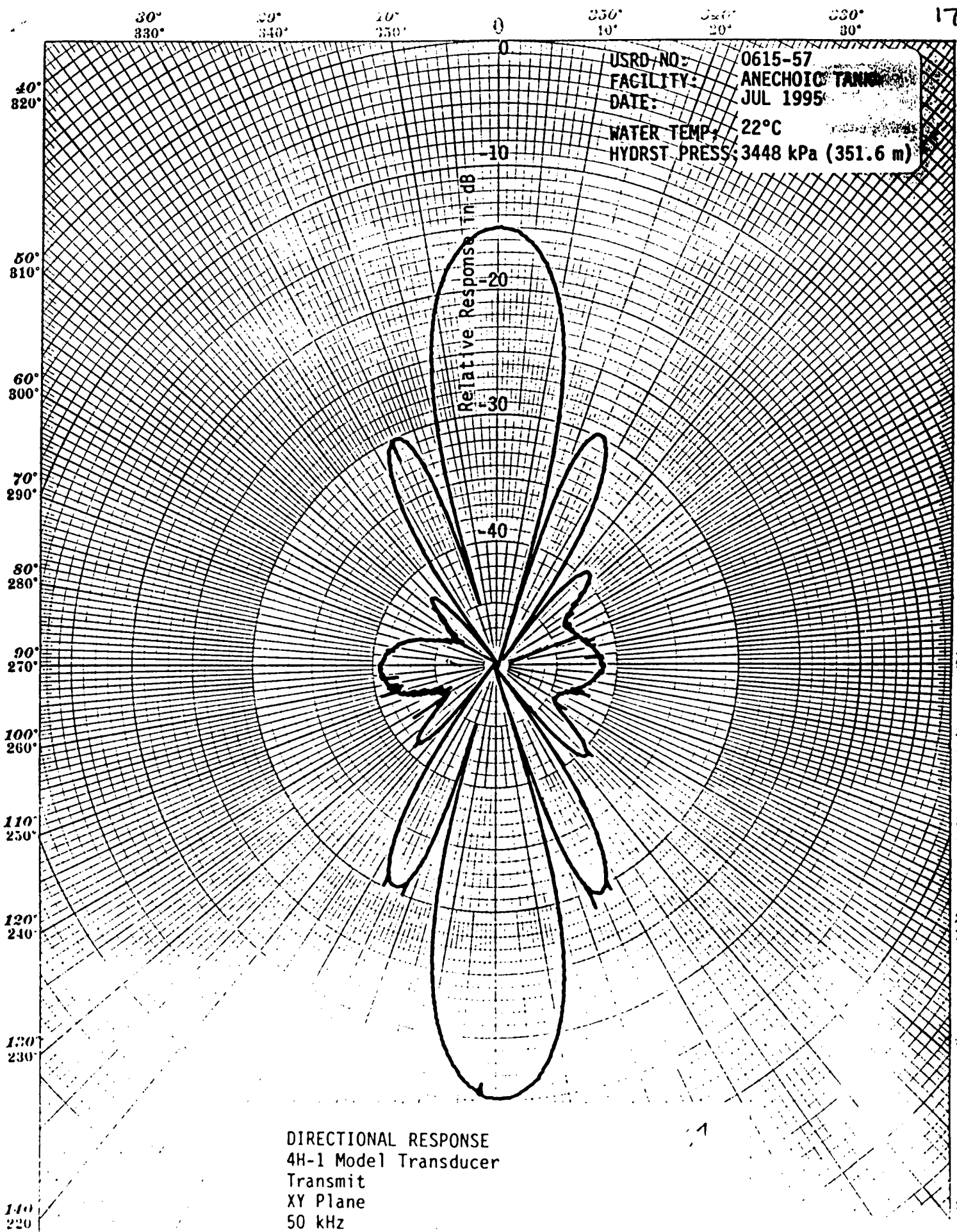




USRD-NO: 0615-56  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 6895 kPa (703.1 m)

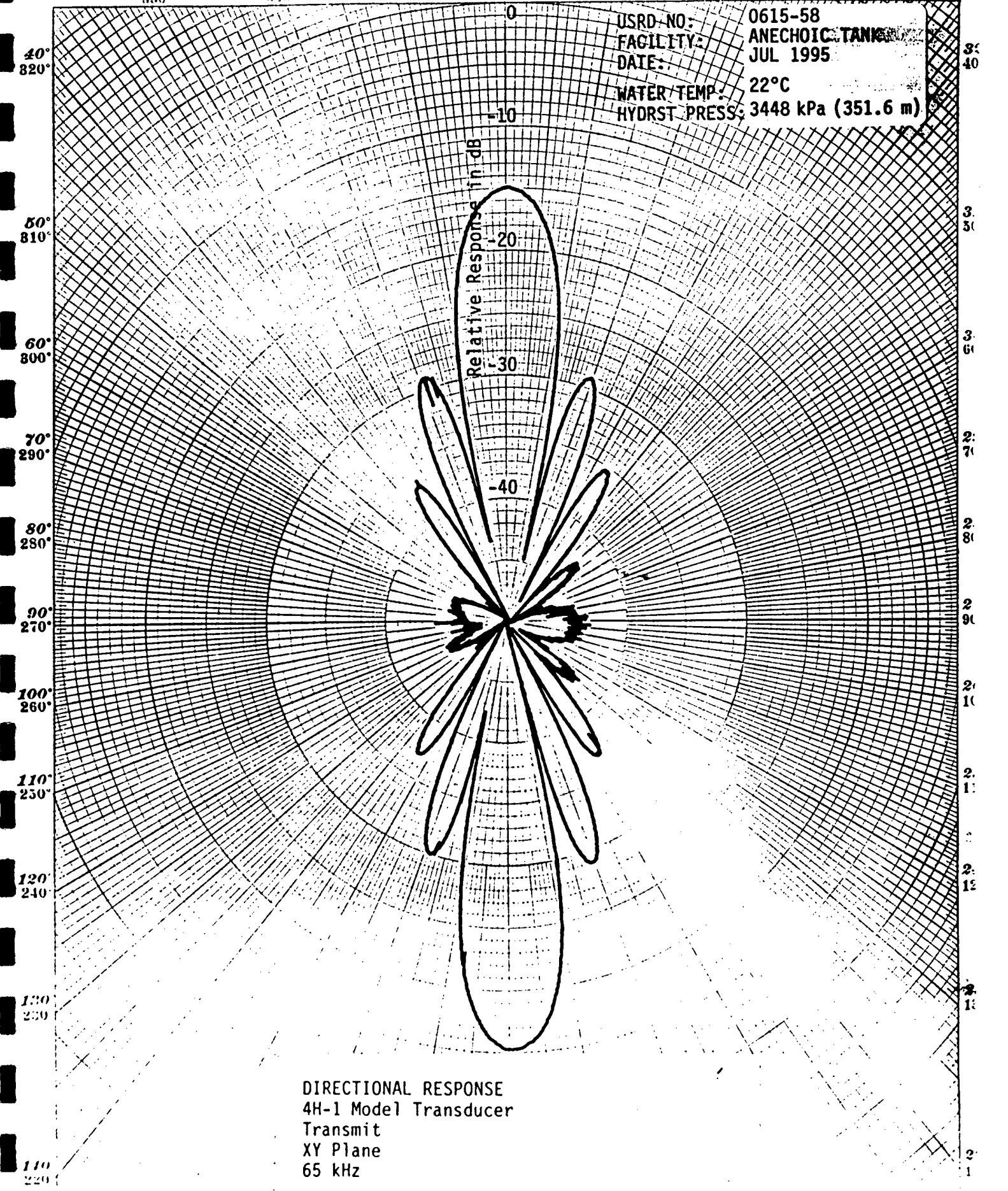


DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
XY Plane  
65 kHz



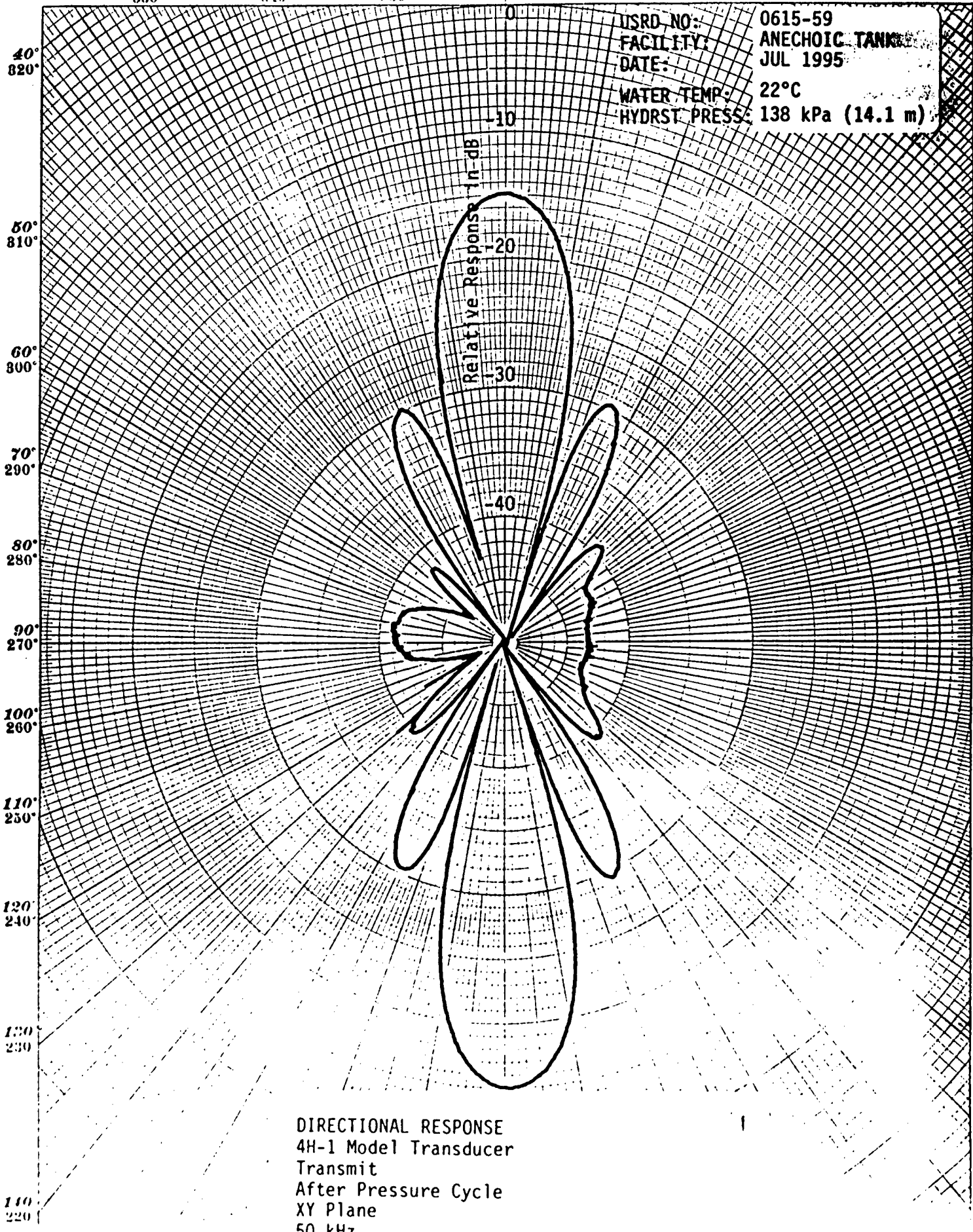
330° 340° 350° 360° 30° 310° 320°

USRD NO: 0615-58  
 FACILITY: ANECHOIC TANK  
 DATE: JUL 1995  
 WATER TEMP: 22°C  
 HYDRST PRESS: 3448 kPa (351.6 m)



DIRECTIONAL RESPONSE  
 4H-1 Model Transducer  
 Transmit  
 XY Plane  
 65 kHz

30° 20° 10° 0° 350° 340° 330° 320° 310° 300°



USRD NO: 0615-59  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 138 kPa (14.1 m)

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
50 kHz



30°  
330°

60°  
340°

90°  
350°

0

330°  
10°

300°  
20°

330°  
30°

20

USRD NO: 0615-60  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 138 kPa (14.1 m)

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB

0

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4H-1 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
65 kHz

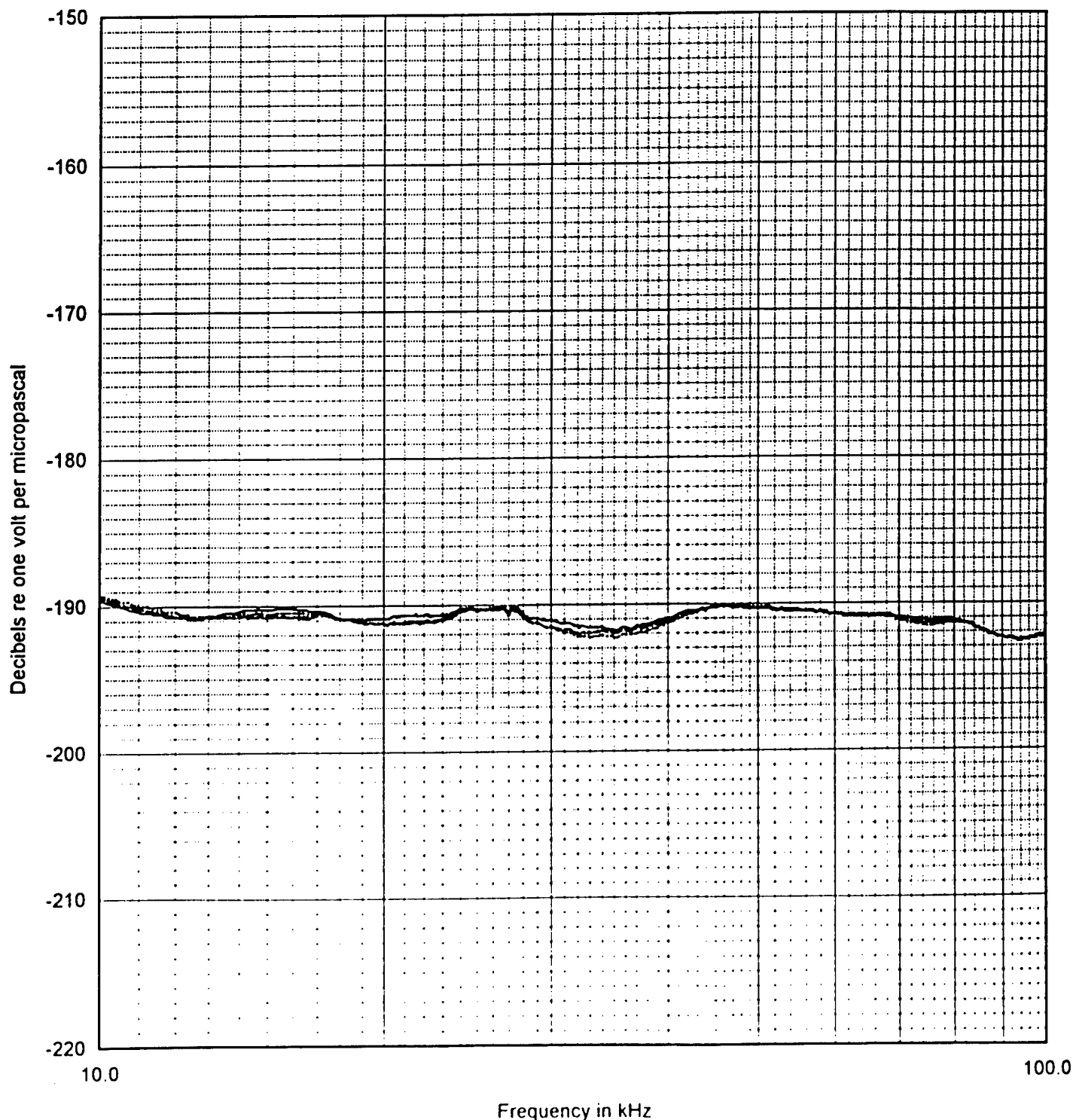
## FREE-FIELD VOLTAGE SENSITIVITY

4H-2 Model Transducer

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle



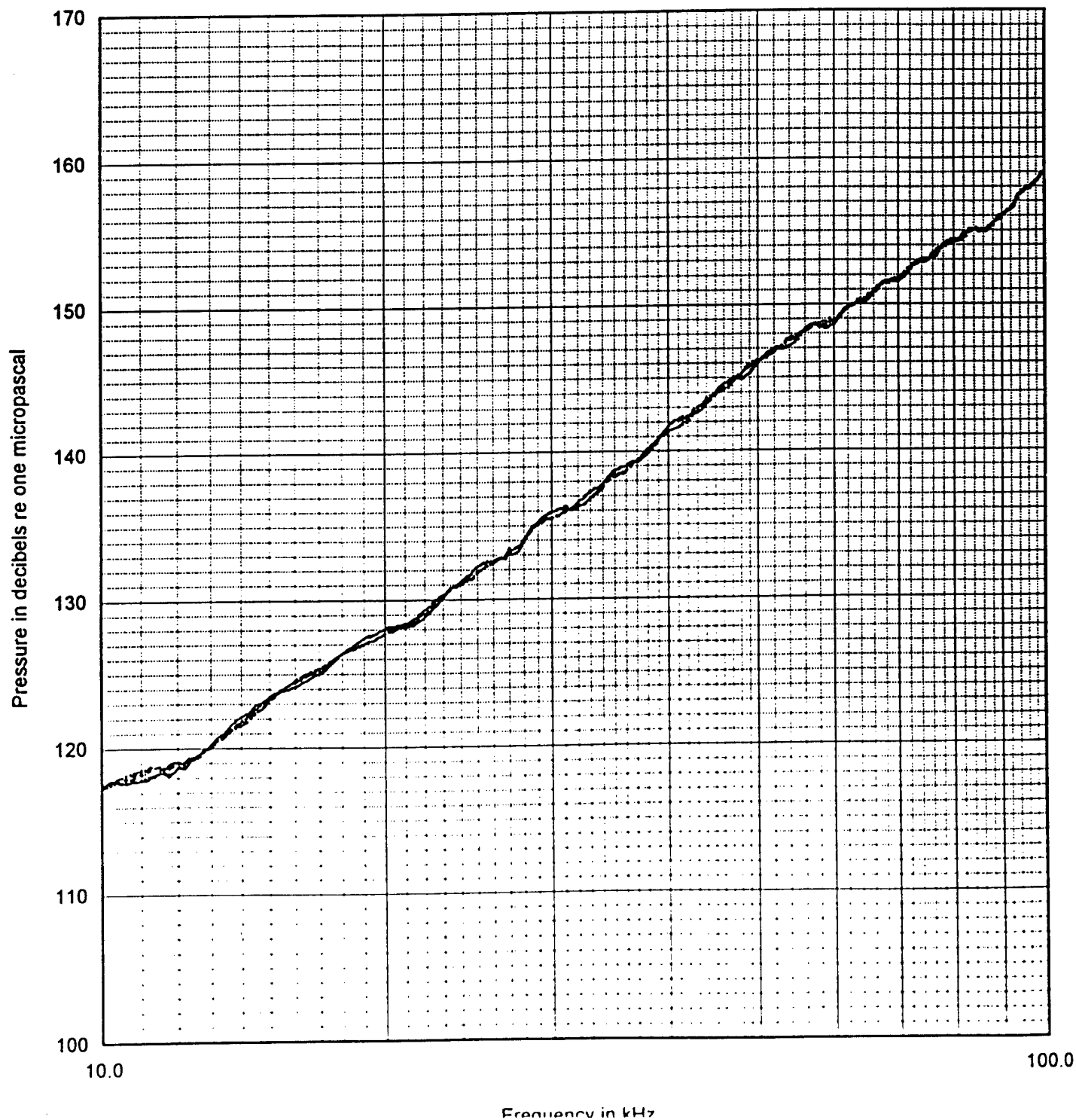
## TRANSMITTING VOLTAGE RESPONSE

4H-2 Model Transducer

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle



2

30°  
330°

60°  
340°

90°  
350°

120°  
30°

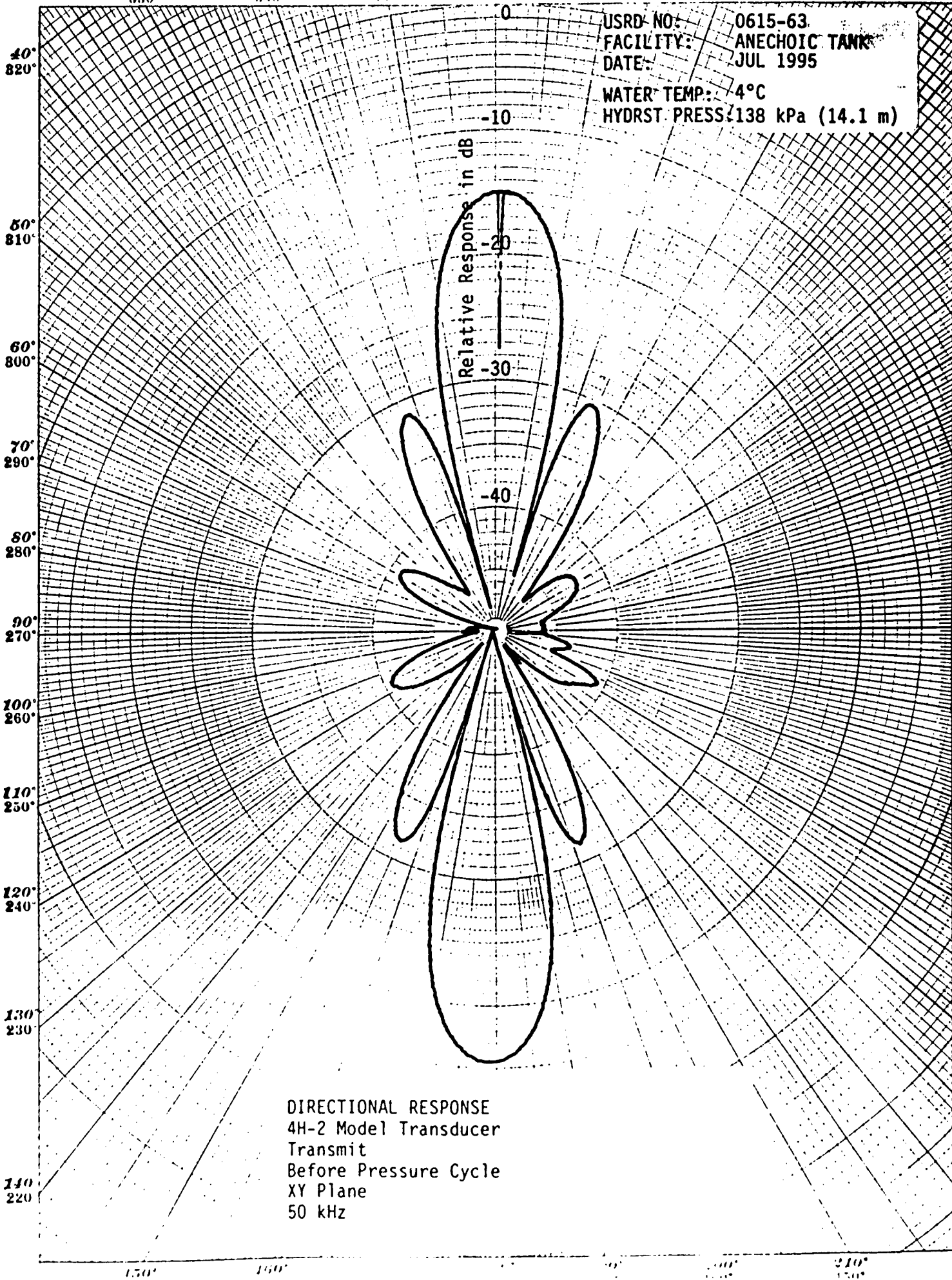
150°  
40°

180°  
50°

210°  
60°

USRD NO: 0615-63  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB



DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
50 kHz



330°  
30°

340°  
30°

350°  
30°

360°  
30°

330°  
30°

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

USRD NO: 0615-64  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

0

-10

-20

-30

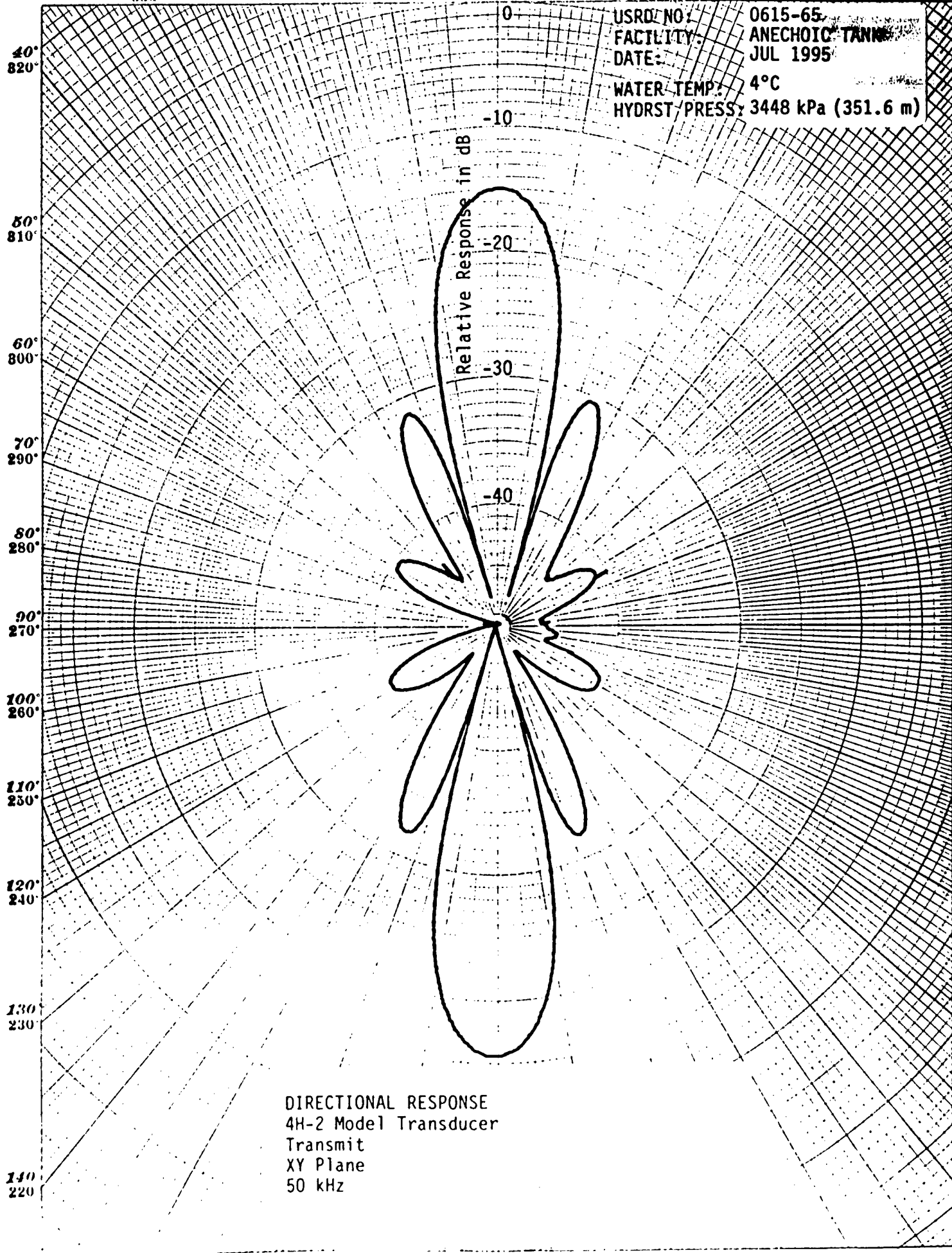
-40

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
65 kHz

34

30° 330° 0° 30° 330° 30°

USRD NO: 0615-65  
 FACILITY: ANECHOIC TANK  
 DATE: JUL 1995  
 WATER TEMP: 4°C  
 HYDRST PRESS: 3448 kPa (351.6 m)



DIRECTIONAL RESPONSE  
 4H-2 Model Transducer  
 Transmit  
 XY Plane  
 50 kHz

3

30°  
330°

20°  
340°

10°  
350°

0°  
360°

330°  
30°

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

35°  
40°

35°  
50°

35°  
60°

25°  
70°

25°  
80°

25°  
90°

25°  
100°

25°  
110°

25°  
120°

25°  
130°

25°  
140°

USRD NO: 0615-66  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMPE: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
65 kHz

56

30°  
330°

30°  
330°

30°  
330°

30°  
330°

30°  
330°

330°  
30°

USRD NO: 0615-67  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST/ PRESS: 6895 kPa (703.1 m)

40°  
820°

50°  
810°

60°  
800°

70°  
790°

80°  
780°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
50 kHz

55

30°  
330°

30°  
340°

20°  
30°

330°  
30°

USRD NO. 0615-68  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB

0

-10

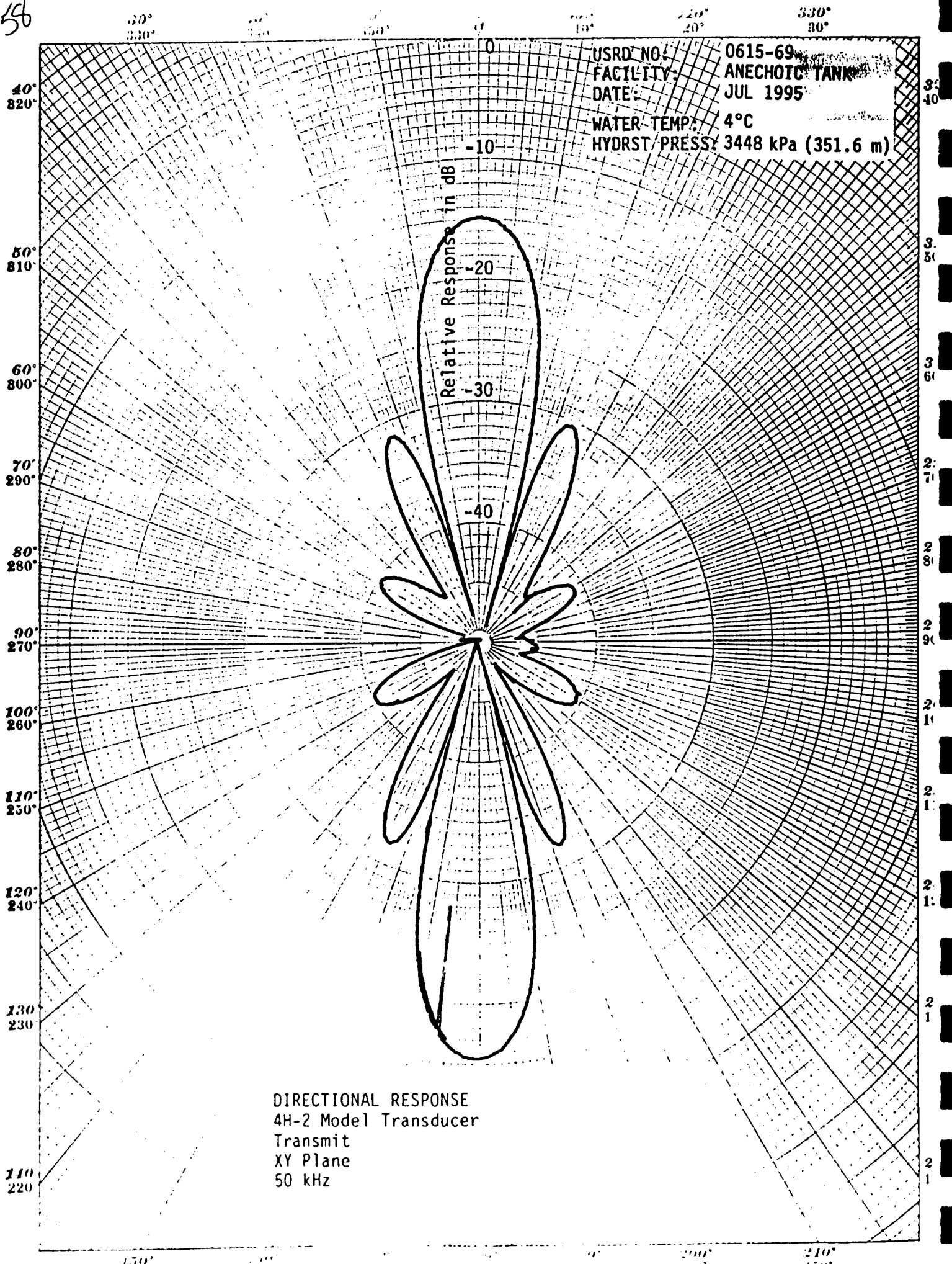
-20

-30

-40

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
65 kHz

56





30°  
330°

60°  
310°

90°  
30°

120°  
330°

150°  
30°

40°  
820°

50°  
810°

60°  
800°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

32  
40

30  
50

30  
60

20  
70

20  
80

20  
90

20  
100

20  
110

20  
120

20  
130

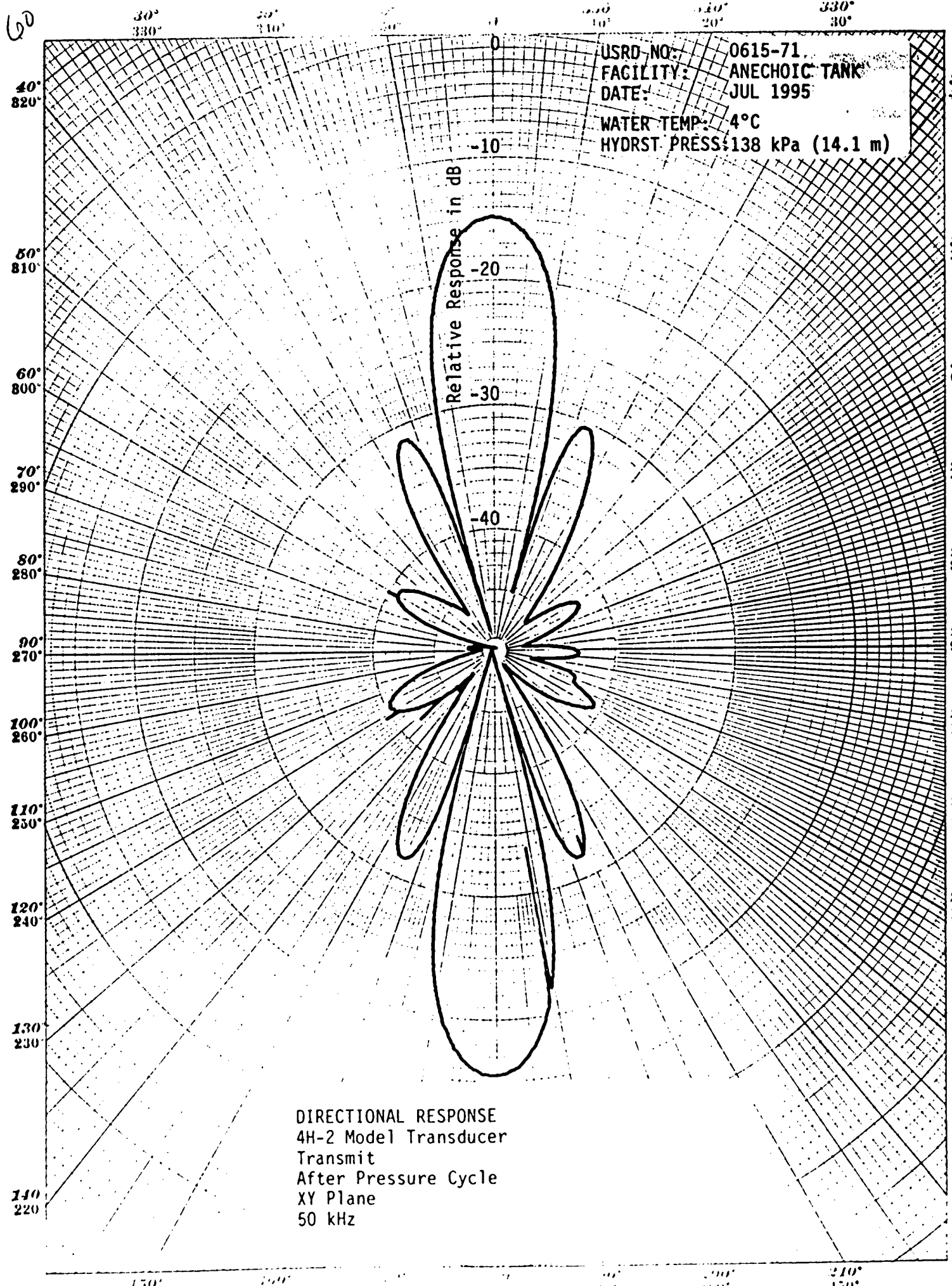
20  
140

USRD NO: 0615-70  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB  
0  
-10  
-20  
-30  
-40

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
65 kHz

60



USRD NO: 0615-71  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

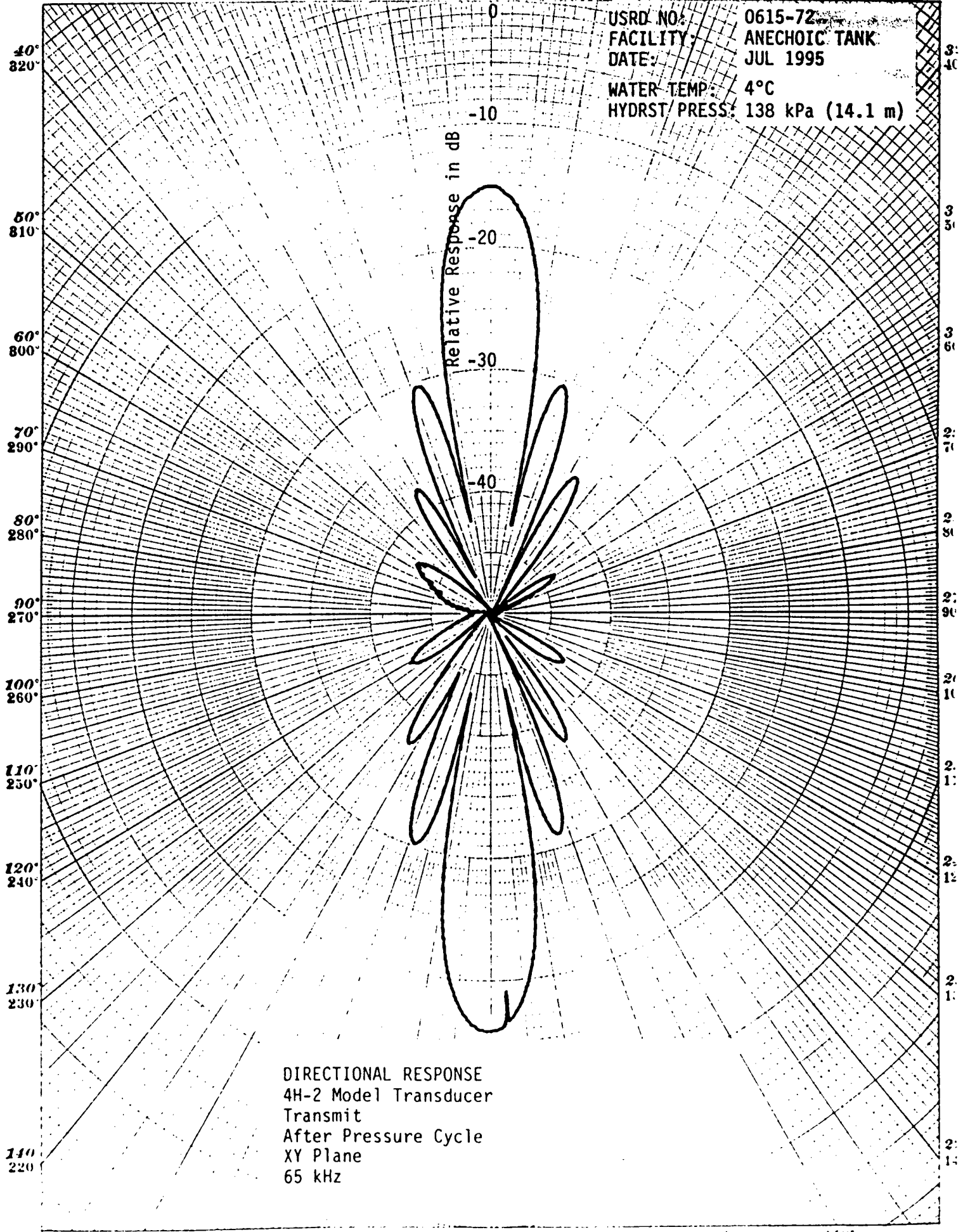
DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
50 kHz



9

30° 330° 0° 30° 330° 30°

USRD NO: 0615-72  
 FACILITY: ANECHOIC TANK  
 DATE: JUL 1995  
 WATER TEMP: 4°C  
 HYDRST PRESS: 138 kPa (14.1 m)



DIRECTIONAL RESPONSE  
 4H-2 Model Transducer  
 Transmit  
 After Pressure Cycle  
 XY Plane  
 65 kHz

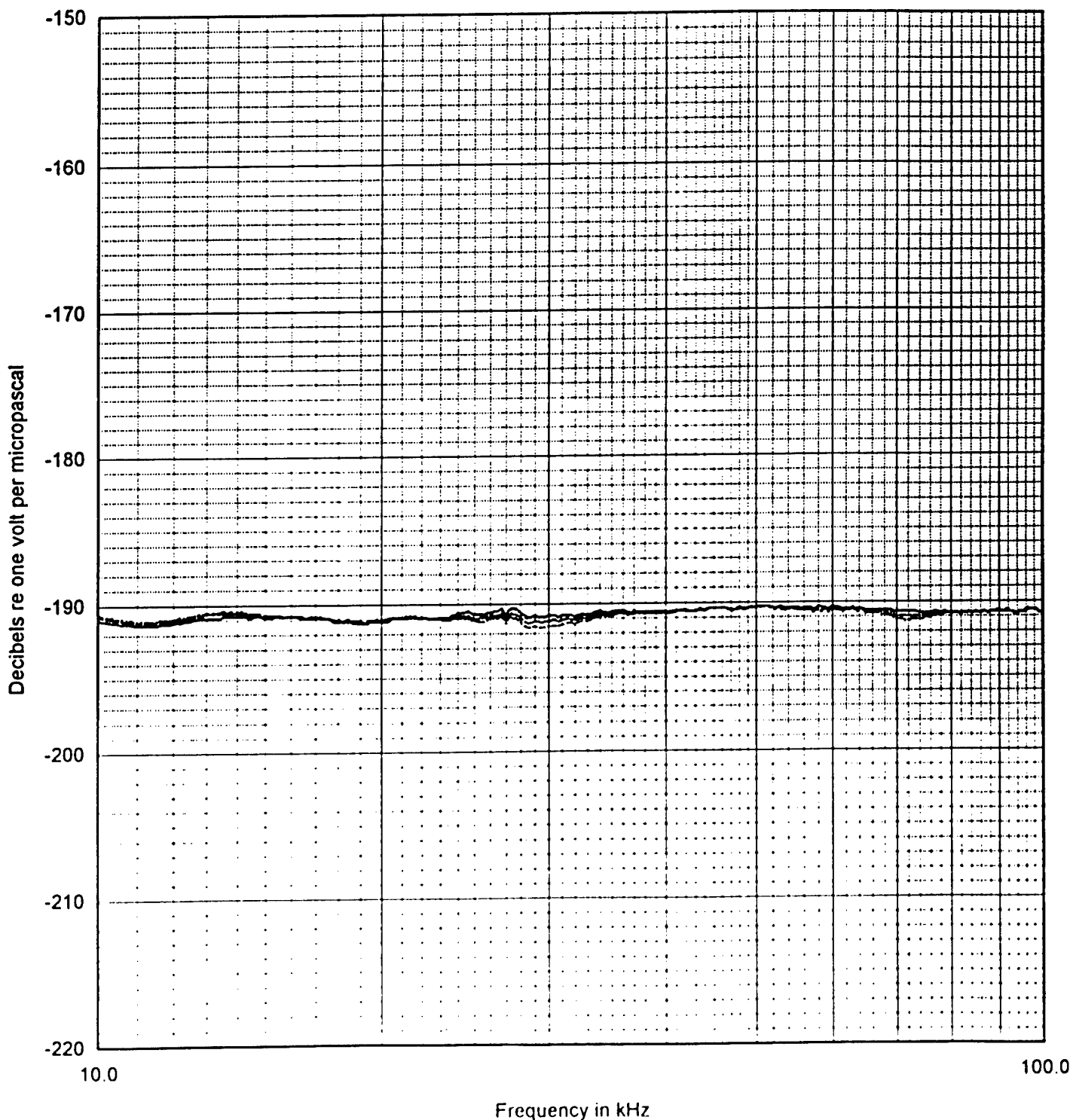
## FREE-FIELD VOLTAGE SENSITIVITY

4H-2 Model Transducer

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 3448 kPa ( 351.6 m)  
----- 138 kPa ( 14.1 m) After Pressure Cycle



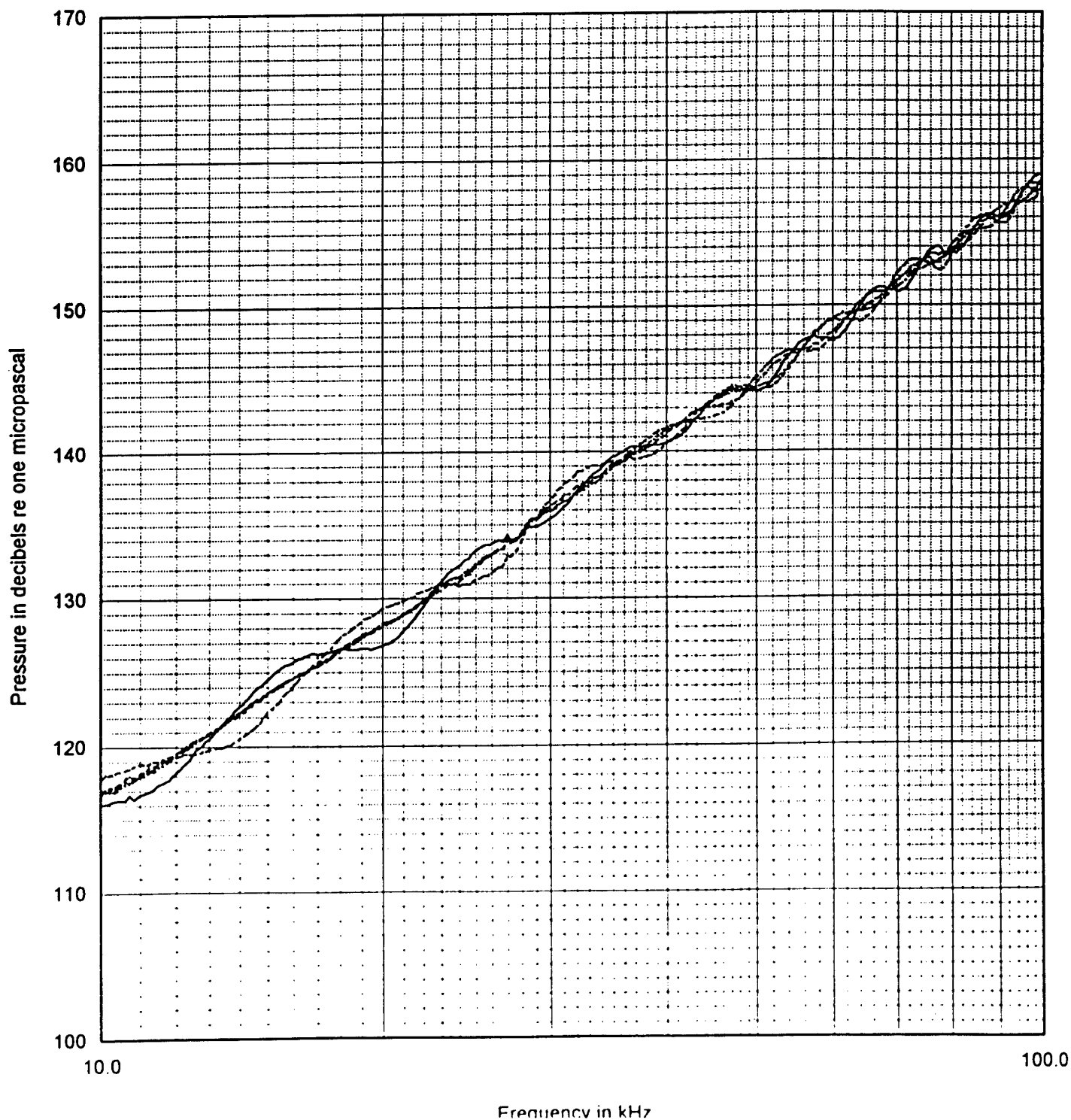
## TRANSMITTING VOLTAGE RESPONSE

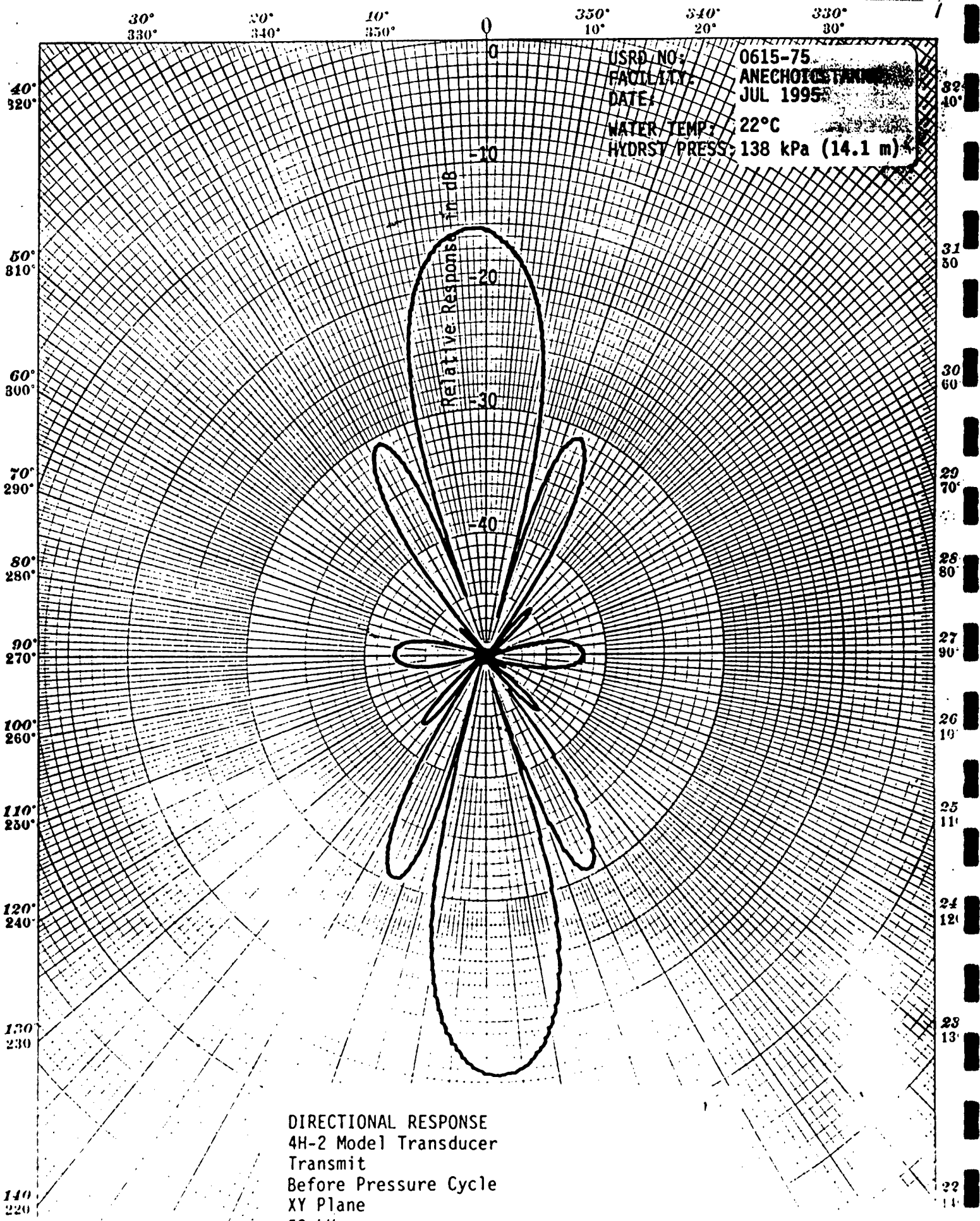
4H-2 Model Transducer

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

- 138 kPa ( 14.1 m) Before Pressure Cycle
- 3448 kPa ( 351.6 m)
- ..... 6895 kPa ( 703.1 m)
- - - - - 3448 kPa ( 351.6 m)
- ..... 138 kPa ( 14.1 m) After Pressure Cycle





30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

2

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

USRB NO: 0615-76  
FACILITY: ANECHOIC CHAMBER  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

-10

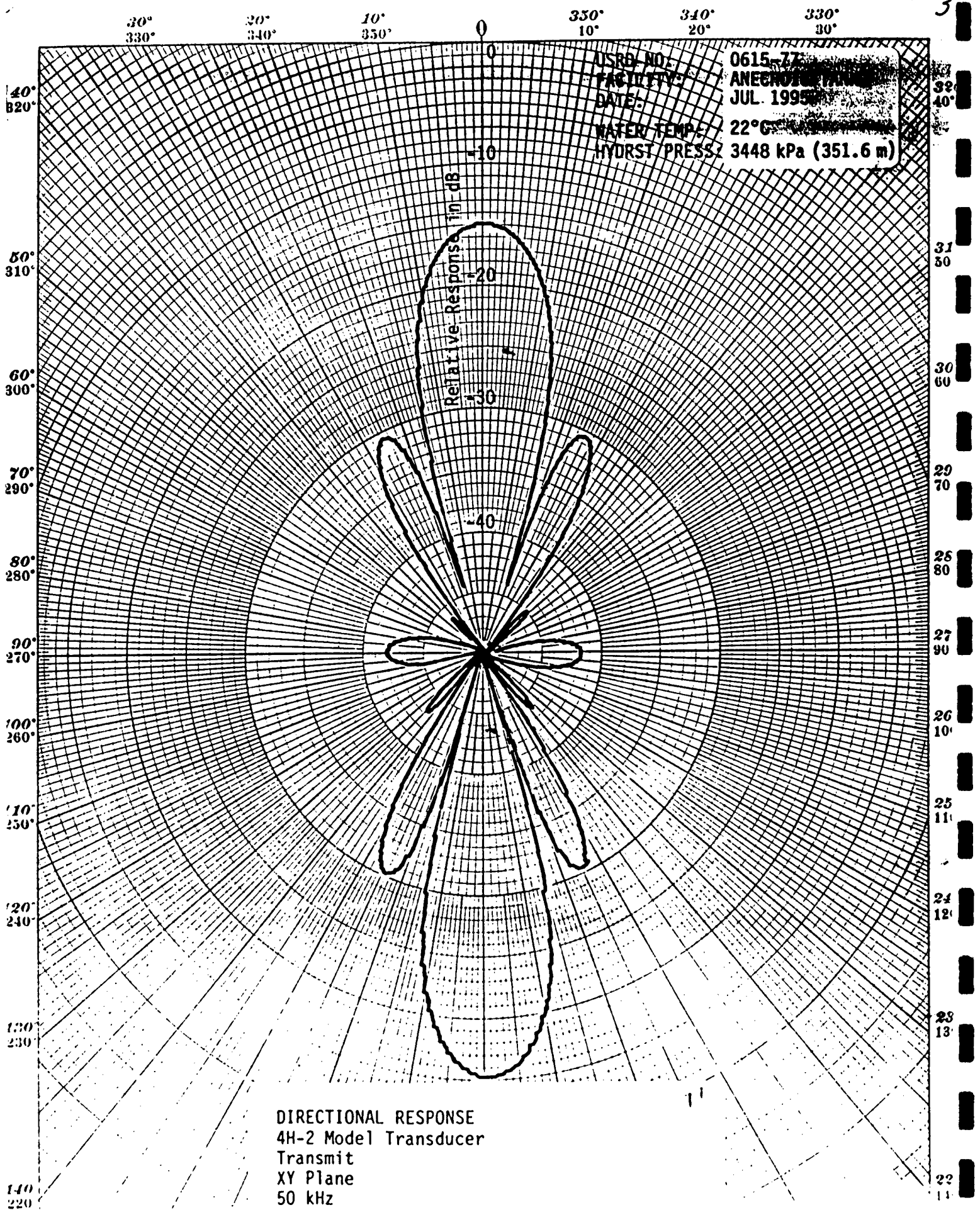
-20

-30

-40

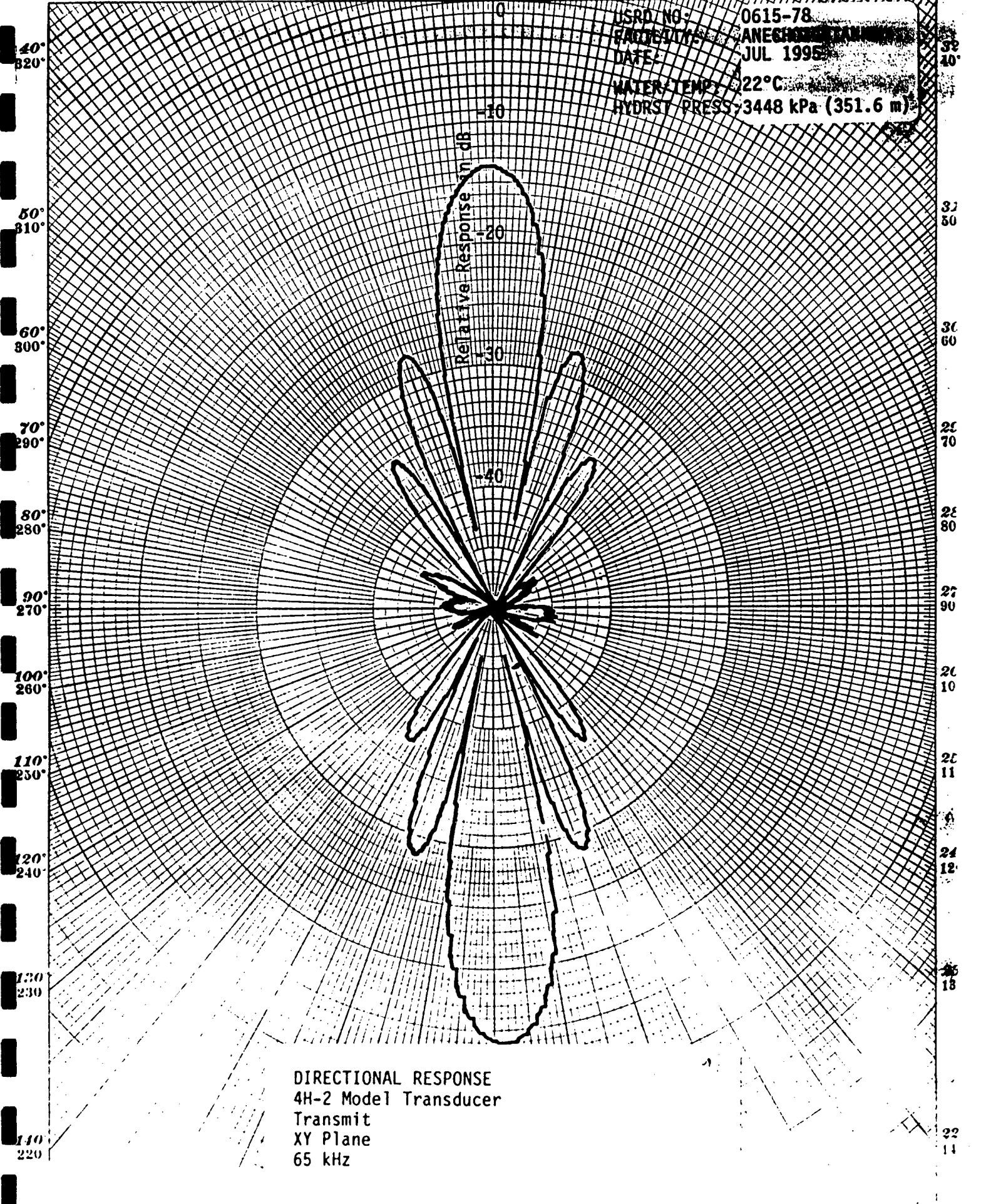
DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
65 kHz





30° 330° 20° 340° 10° 350° 350° 10° 20° 330° 30°

USRD NO: 0615-78  
PROJECT: ANECHOIC CHAMBER  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRS PRESS: 3448 kPa (351.6 m)



DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
65 kHz

150° 160° 170° 180° 190° 200° 210°



30°  
330°

20°  
340°

10°  
350°

350°  
10°

240°  
20°

330°  
30°

40°  
320°

50°  
310°

60°  
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70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

33°  
40°

31°  
50°

30°  
60°

29°  
70°

28°  
80°

27°  
90°

26°  
100°

25°  
110°

24°  
120°

23°  
130°

22°  
140°

USRB NO: 0615-79  
FACILITY: ANECHOIC CHAMBER  
DATE: JUL 1998  
WATER TEMP: 22°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
50 kHz

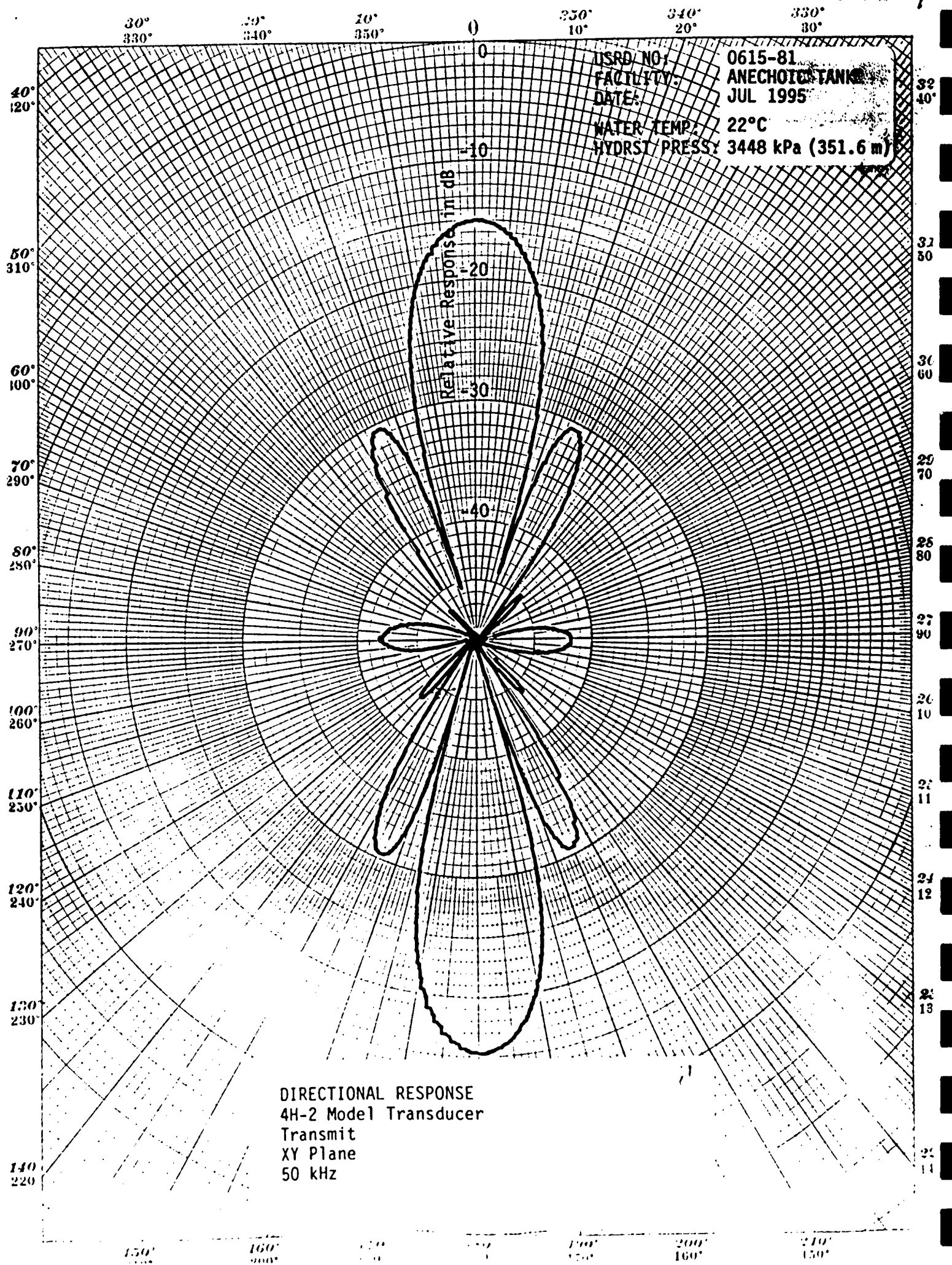
30° 20° 10° 0 350° 340° 330° 320° 310° 300° 290° 280° 270° 260° 250° 240° 230° 220° 210° 200° 190° 180° 170° 160° 150°

USRD NO: 0615-80  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRS PRESS: 6895 kPa (703.1 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
65 kHz

70



30° 330°    50° 340°    10° 350°    0 10°    350° 10°    340° 20°    330° 30°

USRD NO: 0615-82  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 3448 kPa (351.6 m)

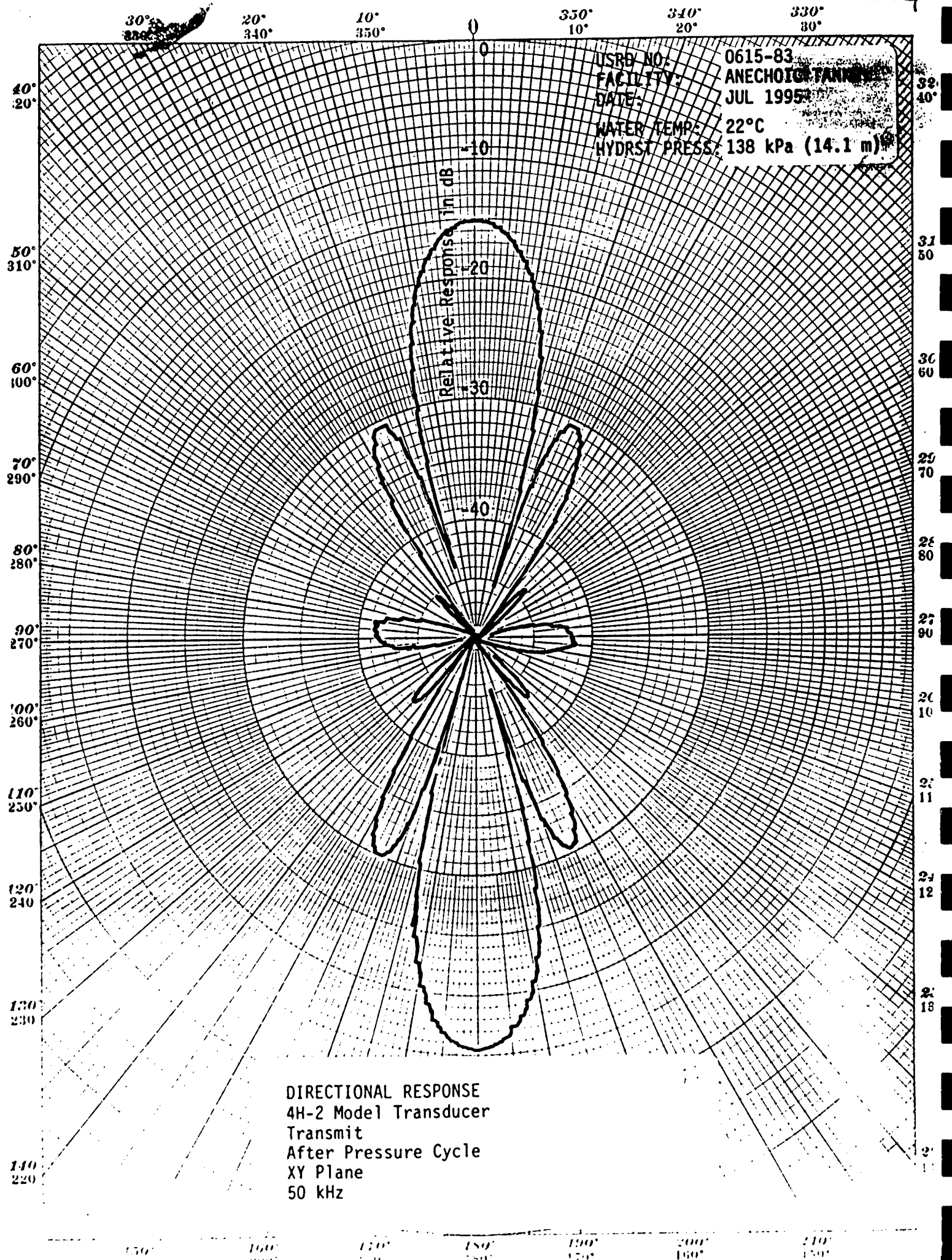
40° 320°  
50° 310°  
60° 300°  
70° 290°  
80° 280°  
90° 270°  
100° 260°  
110° 250°  
120° 240°  
130° 230°  
140° 220°

32 40°  
33 50°  
34 60°  
35 70°  
36 80°  
37 90°  
38 10°  
39 11°  
40 12°  
41 13°  
42 14°

Relative Response in dB

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
XY Plane  
65 kHz





30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

10

USRD NO: 0615-84  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 22°C  
HYDROST PRESS: 138 kPa (14.1 m)

40°  
320°50°  
310°60°  
300°70°  
290°80°  
280°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
4H-2 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
65 kHz

150°  
210°160°  
200°170°  
190°180°  
180°190°  
170°200°  
160°210°  
150°

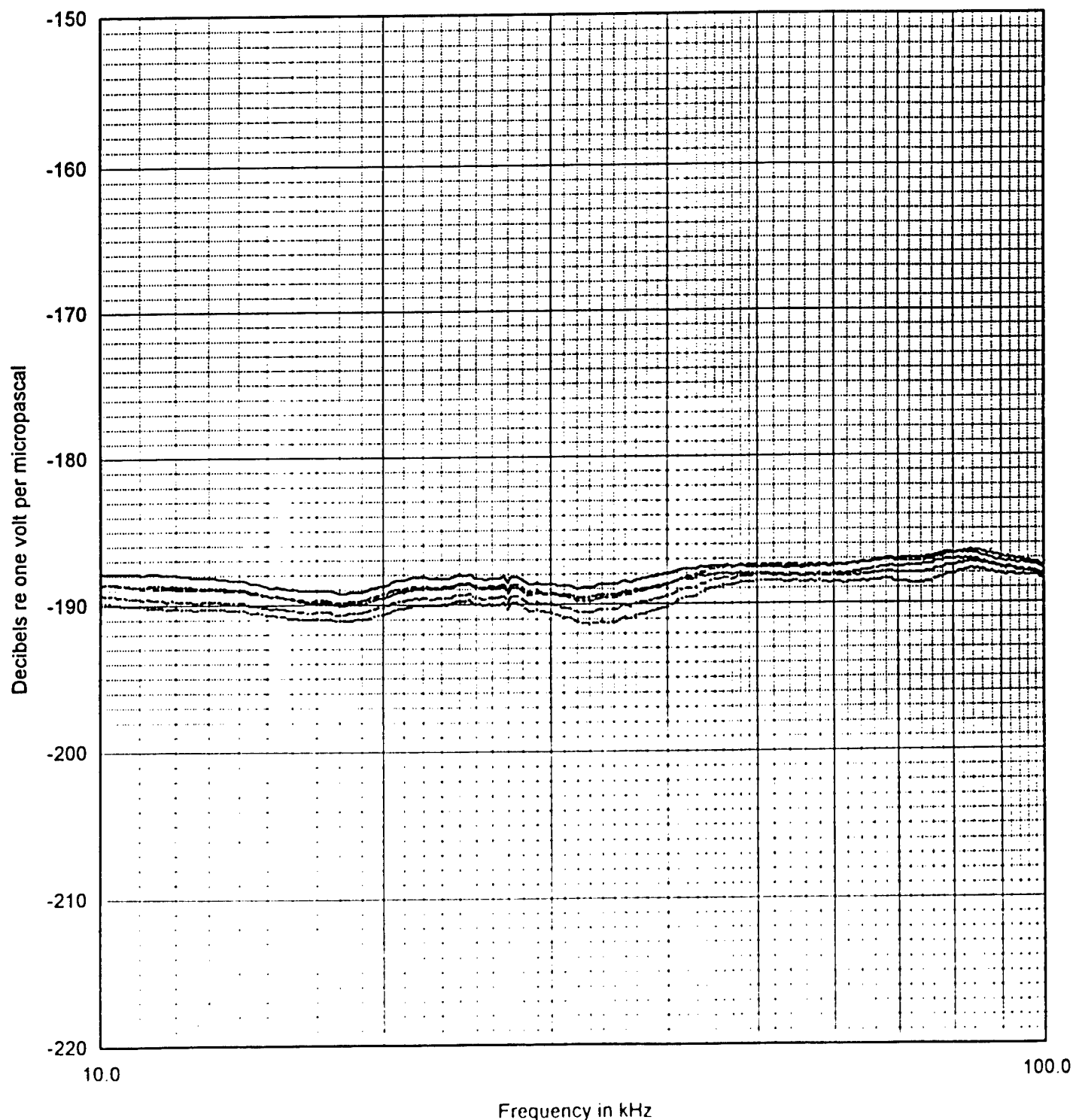
## FREE-FIELD VOLTAGE SENSITIVITY

430 Model Transducer

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 3448 kPa ( 351.6 m)  
..... 138 kPa ( 14.1 m) After Pressure Cycle





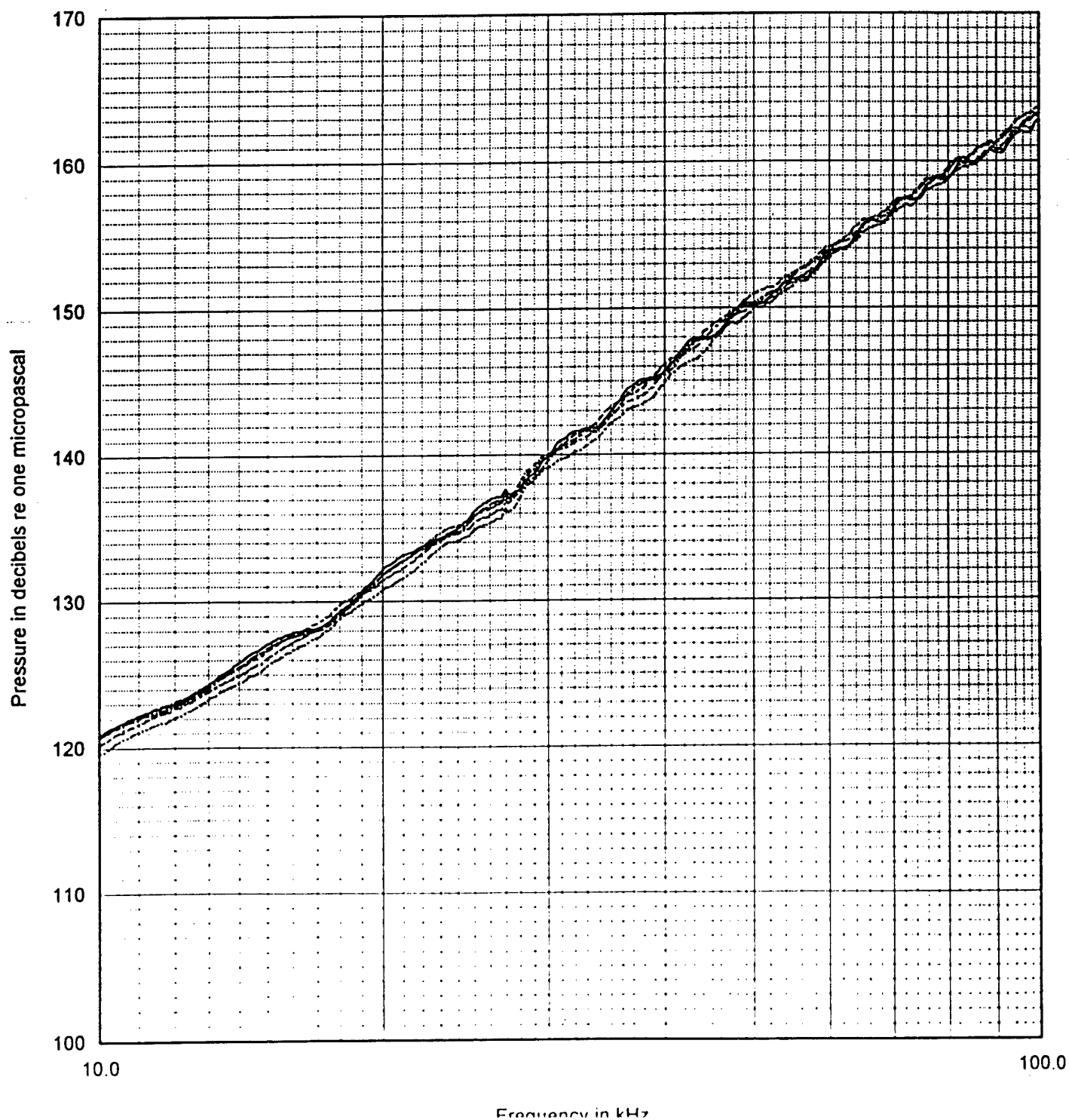
## TRANSMITTING VOLTAGE RESPONSE

430 Model Transducer

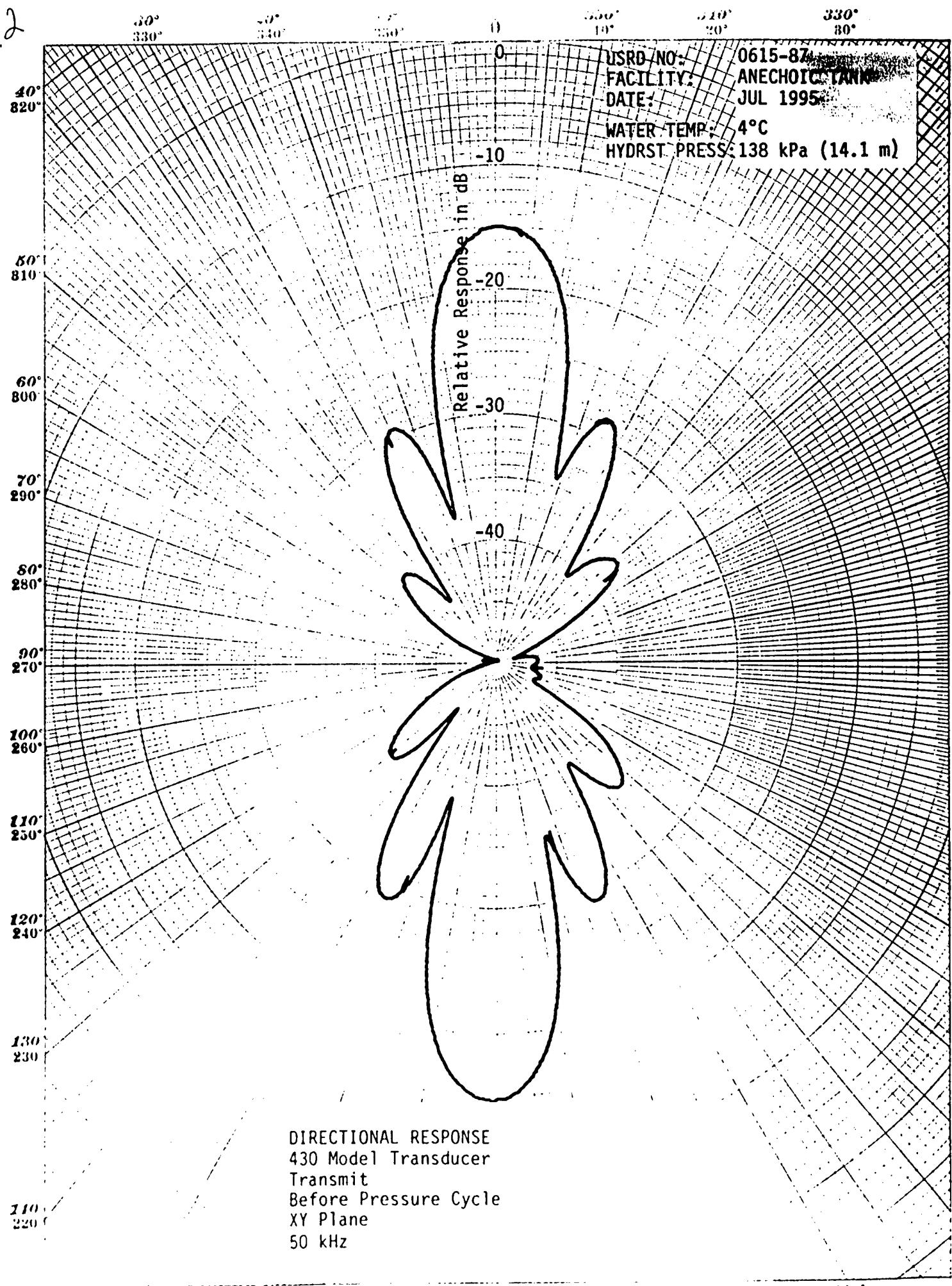
Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

———— 138 kPa ( 14.1 m) Before Pressure Cycle  
- - - - - 3448 kPa ( 351.6 m)  
- - - - - 6895 kPa ( 703.1 m)  
- - - - - 3448 kPa ( 351.6 m)  
- - - - - 138 kPa ( 14.1 m) After Pressure Cycle



2



30°  
330°50°  
340°70°  
350°

0°

50°  
10°510°  
20°330°  
30°

USRD NO: 0615-88  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
430 Model Transducer  
Transmit  
Before Pressure Cycle  
XY Plane  
65 kHz

4

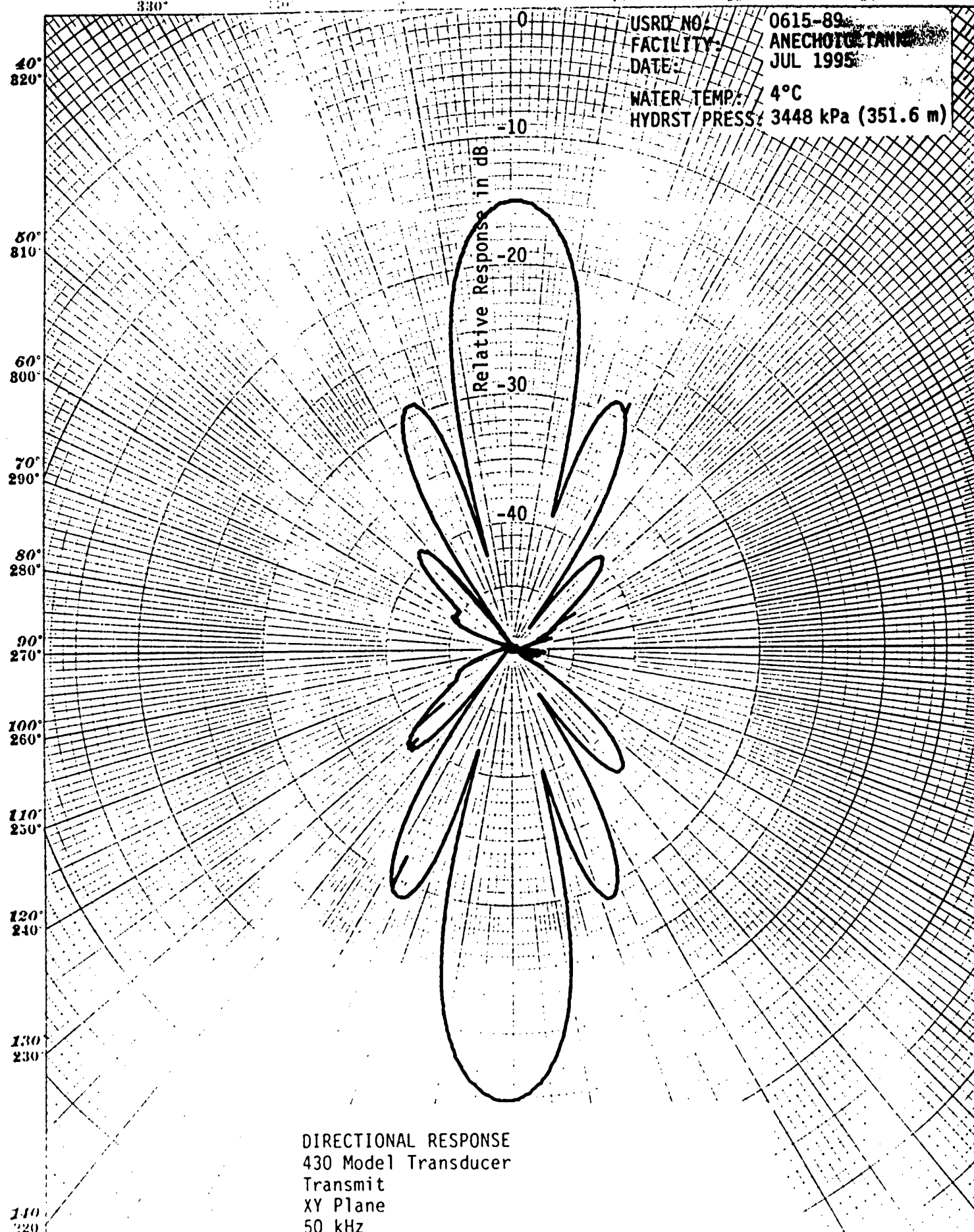
30°  
330°

10°

20°

330°  
30°

USRD NO. 0615-89  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST/PRESS: 3448 kPa (351.6 m)



3

30°  
330°

30°  
310°

30°  
300°

0°

30°  
10°

30°  
20°

30°  
30°

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

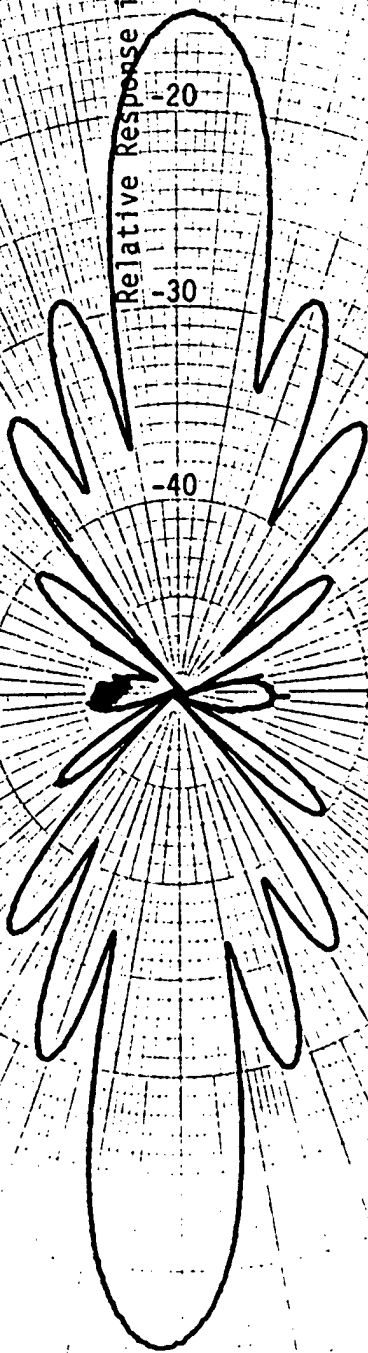
120°  
240°

130°  
230°

140°  
220°

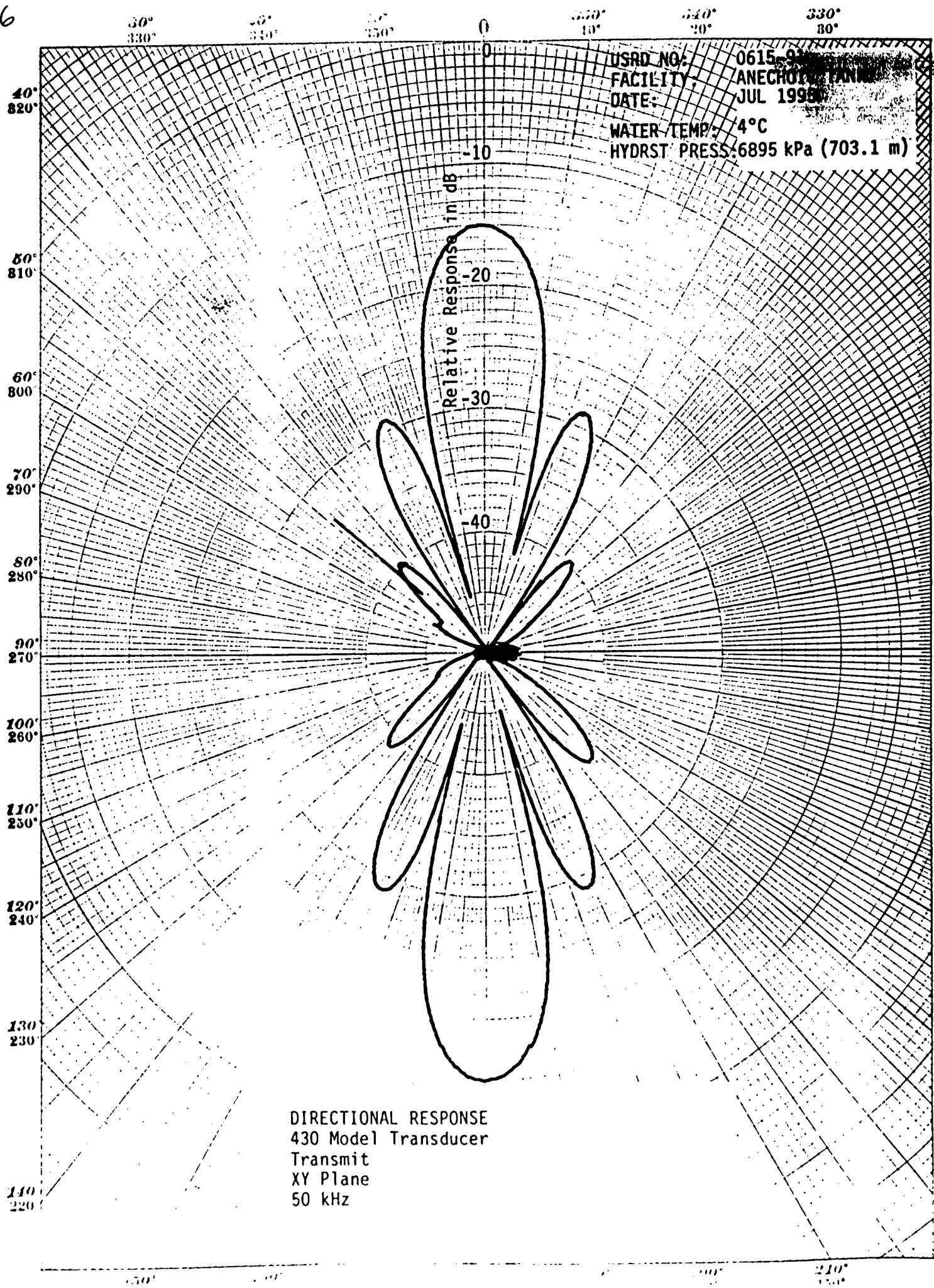
USRD NO: 0615-99  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB



DIRECTIONAL RESPONSE  
430 Model Transducer  
Transmit  
XY Plane  
65 kHz

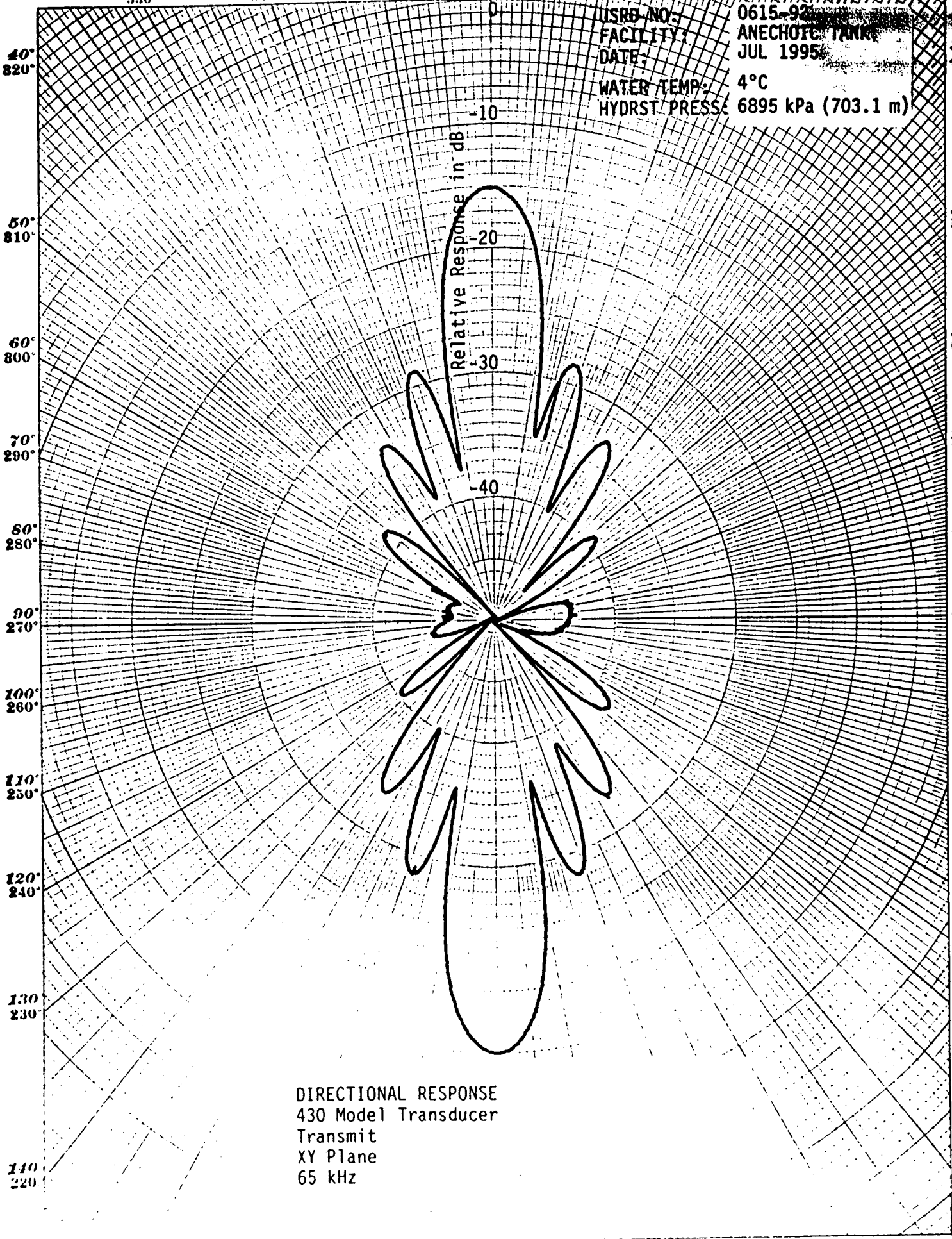
6





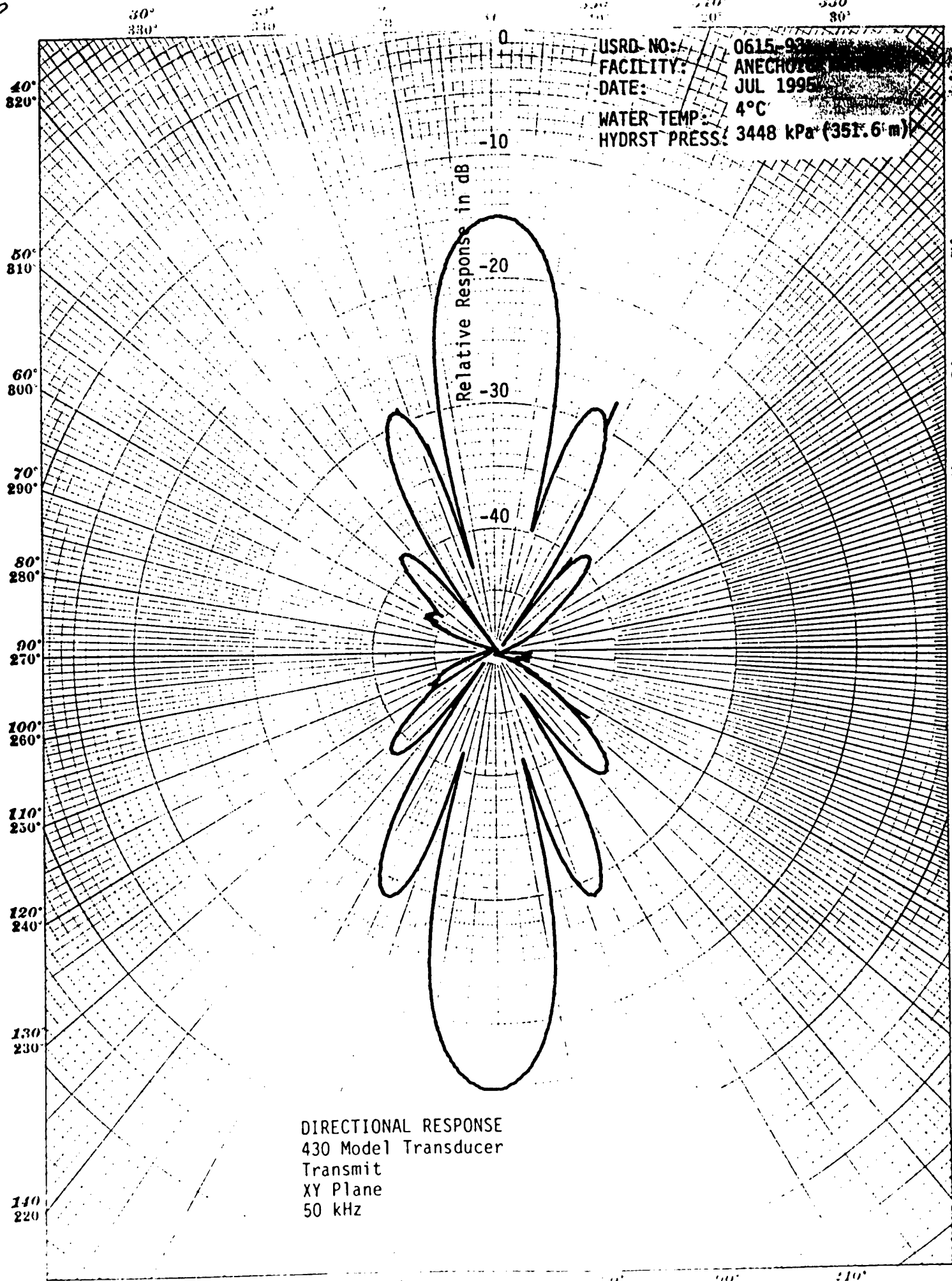
30°	20°	10°	0°	350°	340°	330°
330°	340°	350°	10°	20°	30°	

USRB NO:	0615-92
FACILITY:	ANECHOTE TANK
DATE:	JUL 1995
WATER TEMP:	4°C
HYDRST PRESS:	6895 kPa (703.1 m)



DIRECTIONAL RESPONSE  
430 Model Transducer  
Transmit  
XY Plane  
65 kHz





30°  
330°

20°  
340°

10°  
350°

0°  
10°

340°  
20°

330°  
30°

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

USRB NO: 0615-94  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
430 Model Transducer  
Transmit  
XY Plane  
65 kHz

50

30°  
330°60°  
340°90°  
350°120°  
0°150°  
10°180°  
20°210°  
30°40°  
320°50°  
310°60°  
300°70°  
290°80°  
280°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°

USRB NO: 0615  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

Relative Response in dB

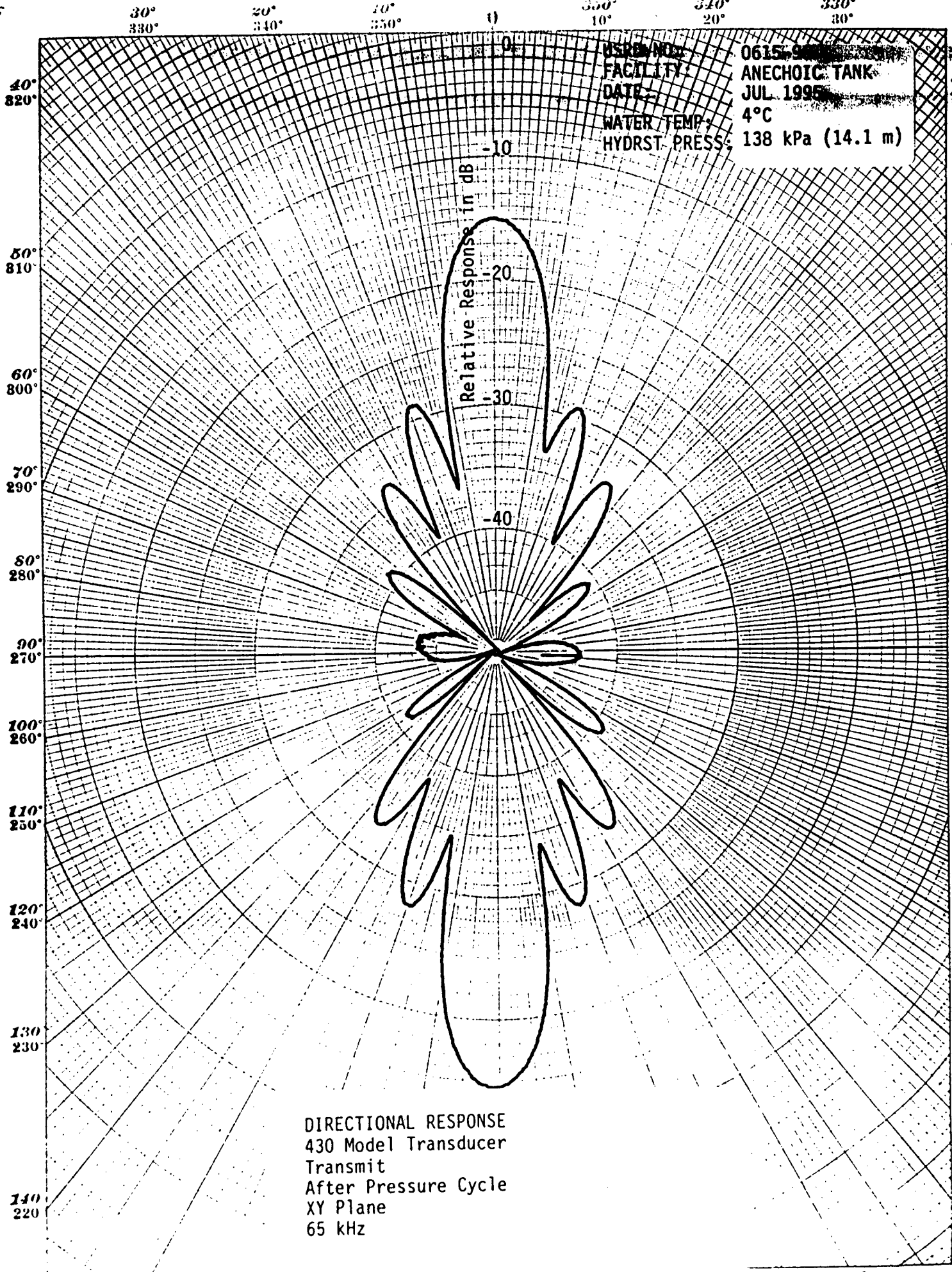
-10

-20

-30

-40

DIRECTIONAL RESPONSE  
430 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
50 kHz



USRB NO: 0615-9000  
FACILITY: ANECHOIC TANK  
DATE: JUL 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 138 kPa (14.1 m)

DIRECTIONAL RESPONSE  
430 Model Transducer  
Transmit  
After Pressure Cycle  
XY Plane  
65 kHz

## COORDINATE SYSTEM FOR TRANSDUCER OR PANEL ORIENTATION

The left-handed coordinate system in the sketch below is affixed to the transducer or panel and moves with its physical position. The angle ( $\theta, \phi$ ) denotes the direction of sound propagation. Measurements are made with sound propagated parallel to the positive X axis ( $\theta = 90^\circ, \phi = 0^\circ$ ) unless otherwise specified.

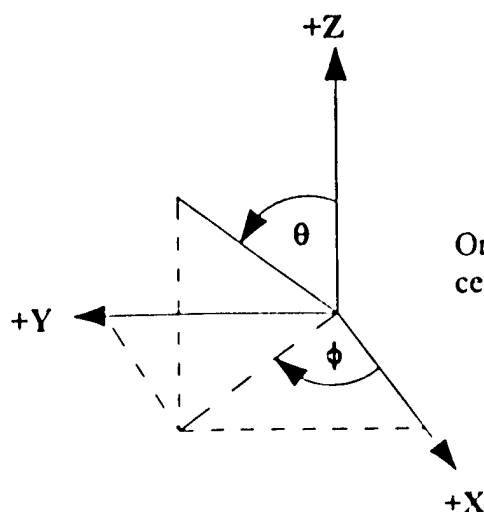
For some measurements, the position of an auxiliary transducer may be specified in terms of cartesian coordinates X, Y, and Z.

Transducers and panels are oriented as follows:

ACOUSTIC SURFACE	ORIENTATION
Cylinder	The cylindrical axis is the Z axis; a reference mark for the +Z direction and for another axis is specified.
Plane	The plane or piston face is in the YZ plane, with the X axis normal to the face at the geometric center. A reference mark in the YZ plane is specified.
Sphere	Points on the surface for any two of the three axes are specified.
Other	A sketch of non-conforming configurations is provided.

Directional Response Patterns: Unless otherwise specified, the following apply

POSITION OF AXES OR DIRECTIONS ON POLAR PLOTS						
SPECIFIED PLANE	AXIS OF ROTATION	+ X AXIS	+ Y AXIS	+ Z AXIS	$\theta = 45^\circ$ $\phi = 90^\circ$	$\theta = 45^\circ$ $\phi = 270^\circ$
XY	Z	$0^\circ$	$90^\circ$ CW	UPWARD	—	—
XZ	Y	$0^\circ$	DOWNWARD	$90^\circ$ CW	—	—
YZ	X	UPWARD	$0^\circ$	$90^\circ$ CW	—	—
ROLL	$\theta = 45^\circ$ $\phi = 270^\circ$	$0^\circ$	—	—	$90^\circ$ CW	UPWARD



Origin is at assumed acoustic center of transducer or panel

# Appendix C





DEPARTMENT OF THE NAVY  
NAVAL UNDERSEA WARFARE CENTER  
1176 HOWELL STREET  
NEWPORT RI 02841-1708



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P O BOX 56337  
ORLANDO FL 32856-8337

IN REPLY REFER TO:  
3965  
Ser X72500-0695  
5 DEC 1995

USRD CALIBRATION MEMORANDUM NO. 0695

Subj: MEASUREMENTS ON PIEZOCOMPOSITE TRANSDUCERS SERIALS 3.25, 36S30-1, 36S8-2, 4-29, 4-2P4, AND 7.5

Ref: (a) Fonecon, Mr. T. Howarth of NRL to Mrs. A. Barela of NUWC-USRD, 12 Oct 1995  
(b) NUWC-USRD Job Order No. T72515

Encl: (1) USRD Charts 1 through 120 and Table 1  
(2) USRD Drawing 62785

1. Measurements on the subject transducers were made in the Anechoic Tank Facility during the period 23 through 31 October 1995 as arranged in reference (a). Mr. T. Howarth of the Naval Research Laboratory, Washington, DC was present to specify and assist with the measurements. Funds for this service were provided by reference (b).

2. Free-field voltage sensitivity (FFVS), transmitting voltage response (TVR), and directional response (DR) in the horizontal (XY) plane were measured in the frequency range 2.0 to 200 kHz, at the water temperatures 4 and 22°C, and at hydrostatic pressures to 6895 kPa (703.1 m). Conditions and results of the measurements are presented in enclosure (1).


3. Intermittent "shorting" was observed for piezocomposite transducers serials 3.25, 4-2P4, and 7.5 at pressures of 3448 kPa (351.6 m) and above.

Further dissemination only as directed by  
Commanding Officer, Naval Research  
Laboratory ( 5 DEC 1995 ) or higher DoD  
authority.

3965  
Ser X72500-0695  
5 DEC 1995

USRD CALIBRATION MEMORANDUM NO. 0695

4. Orientation was as described for a piston in enclosure (2). An arrow on the face of the transducer was in the direction of the +Z axis and the cable exited in the -X direction except where otherwise noted.

  
A. E. PAOLERO  
Project Leader

  
R. M. DRAKE  
Head, Acoustic Measurements T&E Branch

Copy to:  
NRL (Code 7135, T. Howarth)  
NUWC-USRD (Code 251, R. Ting)  
(Code 2582)

TABLE 1  
DATA DIRECTORY  
Piezocomposite Transducers

	CHART
Serial 3.25	
4°C	
FFVS .....	1
TVR .....	2
DR .....	3-14
22°C	
FFVS .....	15
TVR .....	16
DR .....	17-24
Serial 36S30-1	
22°C	
TVR .....	25
Serial 36S8-2	
22°C	
TVR .....	26
Serial 4-29	
4°C	
FFVS .....	27
TVR .....	28
DR .....	29-44
22°C	
FFVS .....	45
TVR .....	46
DR .....	47-62

TABLE 1  
Piezocomposite Transducers

	CHART
Serial 4-2P4	
4°C	
FFVS .....	63
TVR .....	64
DR .....	65-78
22°C	
FFVS .....	79
TVR .....	80
DR .....	81-88
Serial 7.5	
4°C	
FFVS .....	89
TVR .....	90
DR .....	91-102
22°C	
FFVS .....	103
TVR .....	104
DR .....	105-120

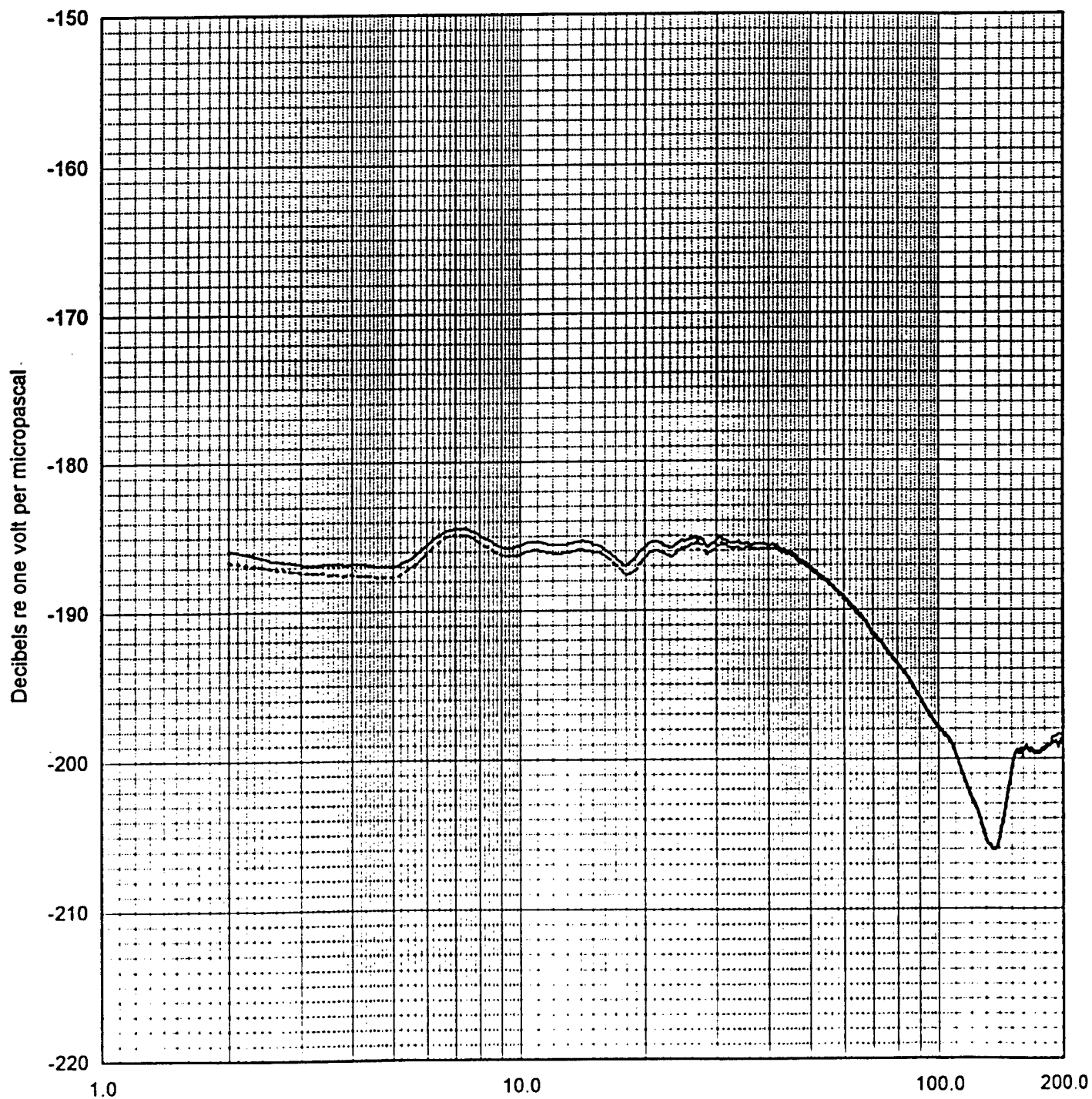
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 3.25

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

—— 16 kPa (1.6 m) Before Pressure  
----- 16 kPa (1.6 m) After Pressure



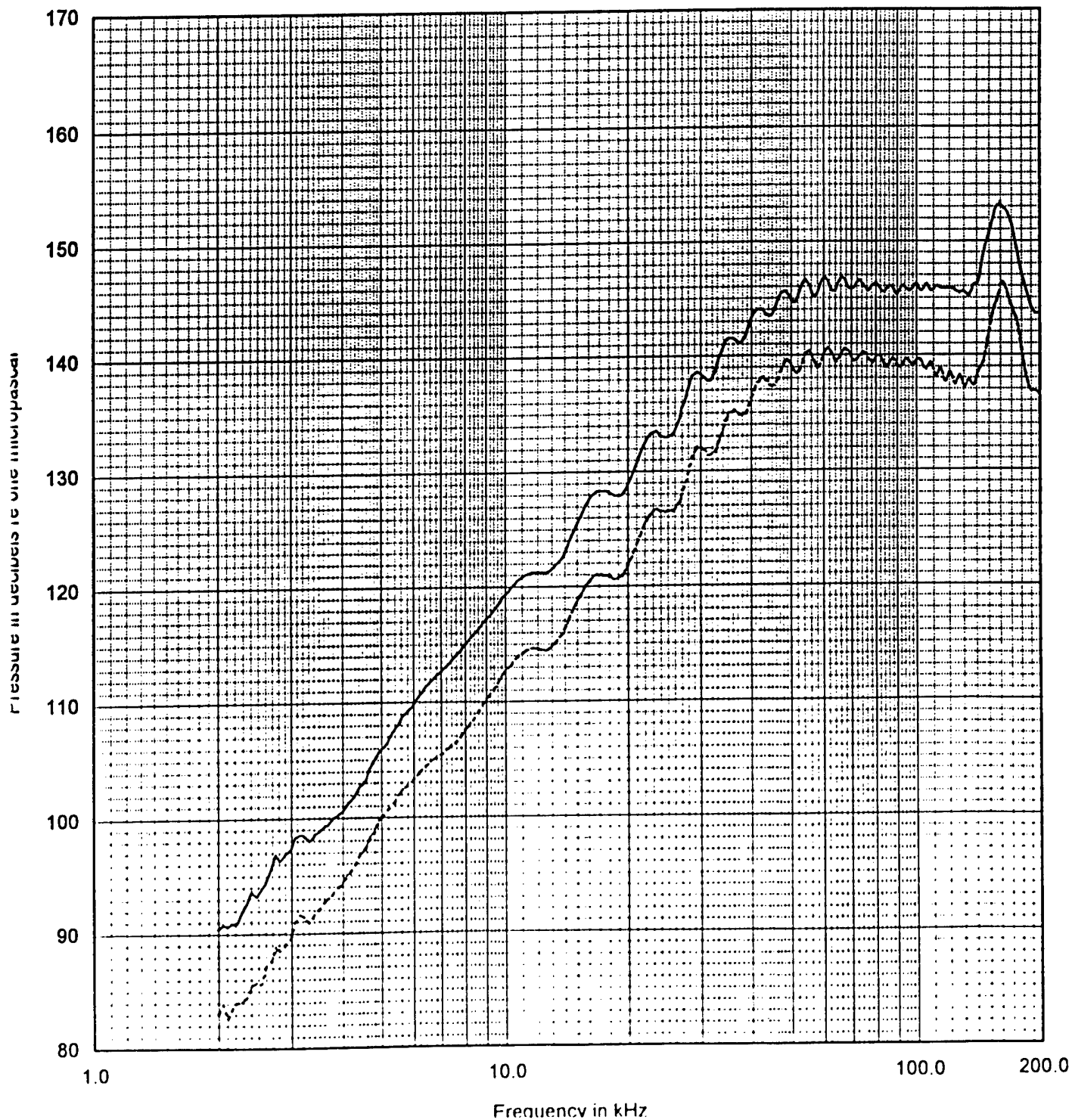
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 3.25

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

—— 16 kPa (1.6 m) Before Pressure  
----- 16 kPa (1.6 m) After Pressure





30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 0° 10° 20° 30°

USRD NO: 0695-3  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

40° 820°  
50° 810°  
60° 800°  
70° 290°  
80° 280°  
90° 270°  
100° 260°  
110° 250°  
120° 240°  
130° 230°  
140° 220°

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999  
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Relative Response in dB  
0  
-10  
-20  
-30  
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
Before Pressure  
XY Plane  
10 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-4  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
Before Pressure  
XY Plane  
20 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-5  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

40°  
820°

50°  
810°

60°  
800°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
Before Pressure  
XY Plane  
50 kHz

150°

160°

170°

180°

190°

200°

210°

170°

30°  
330°

20°  
340°

10°  
350°

0°

300°  
10°

210°  
20°

150°  
30°

USRD NO: 0695-6  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
Before Pressure  
XY Plane  
100 kHz



30°  
330°

20°  
340°

10°  
350°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-7  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

0

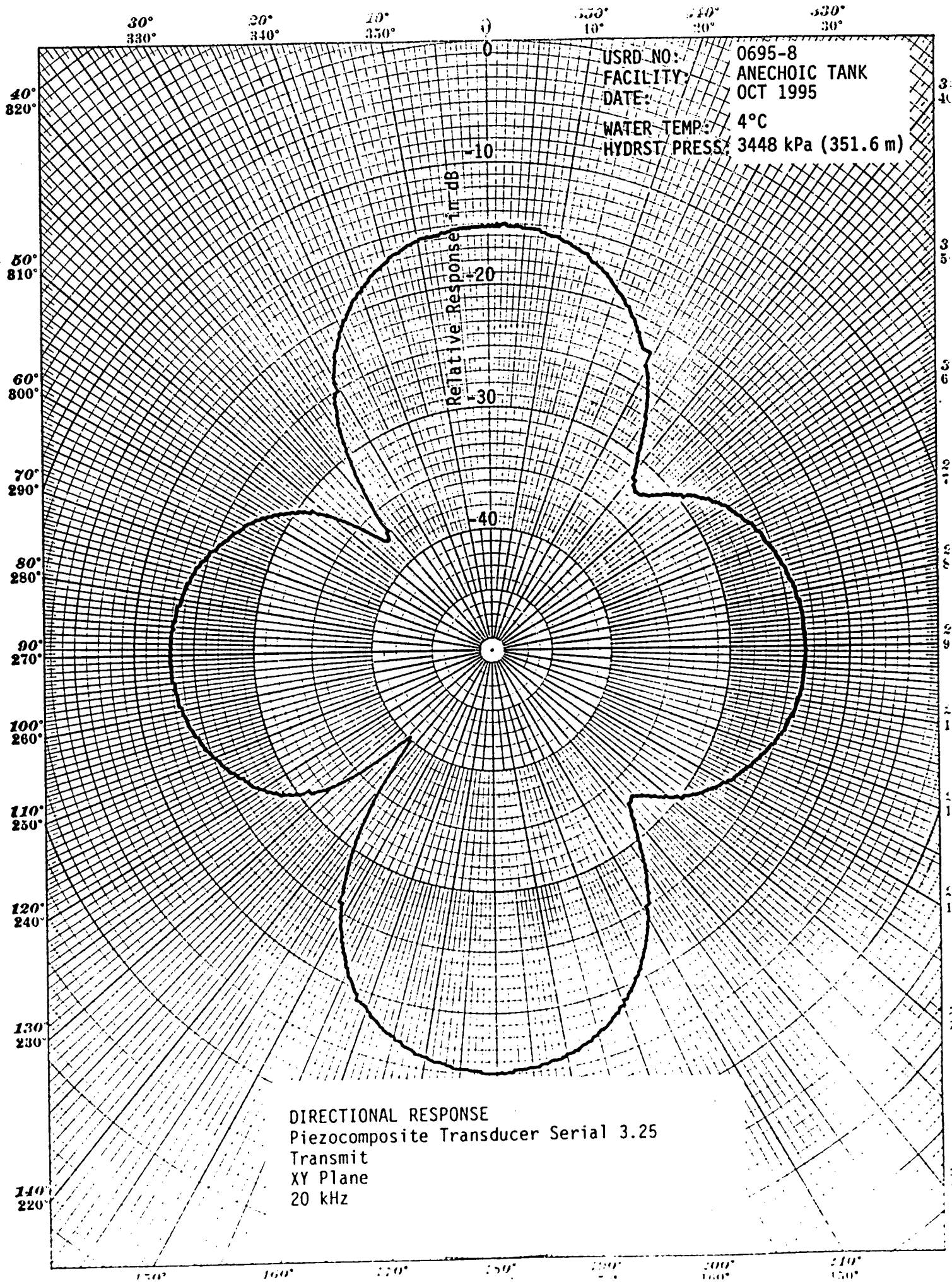
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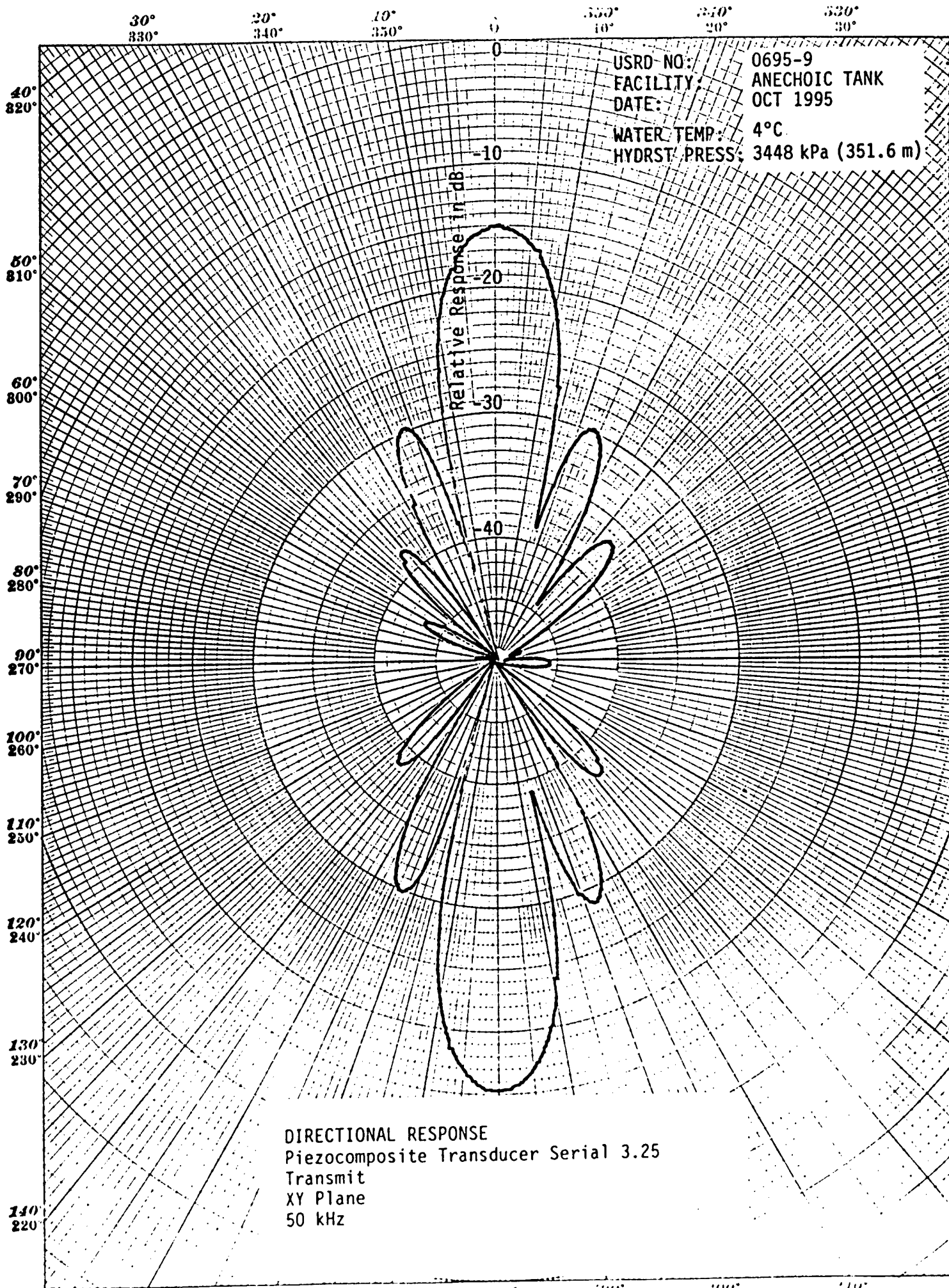
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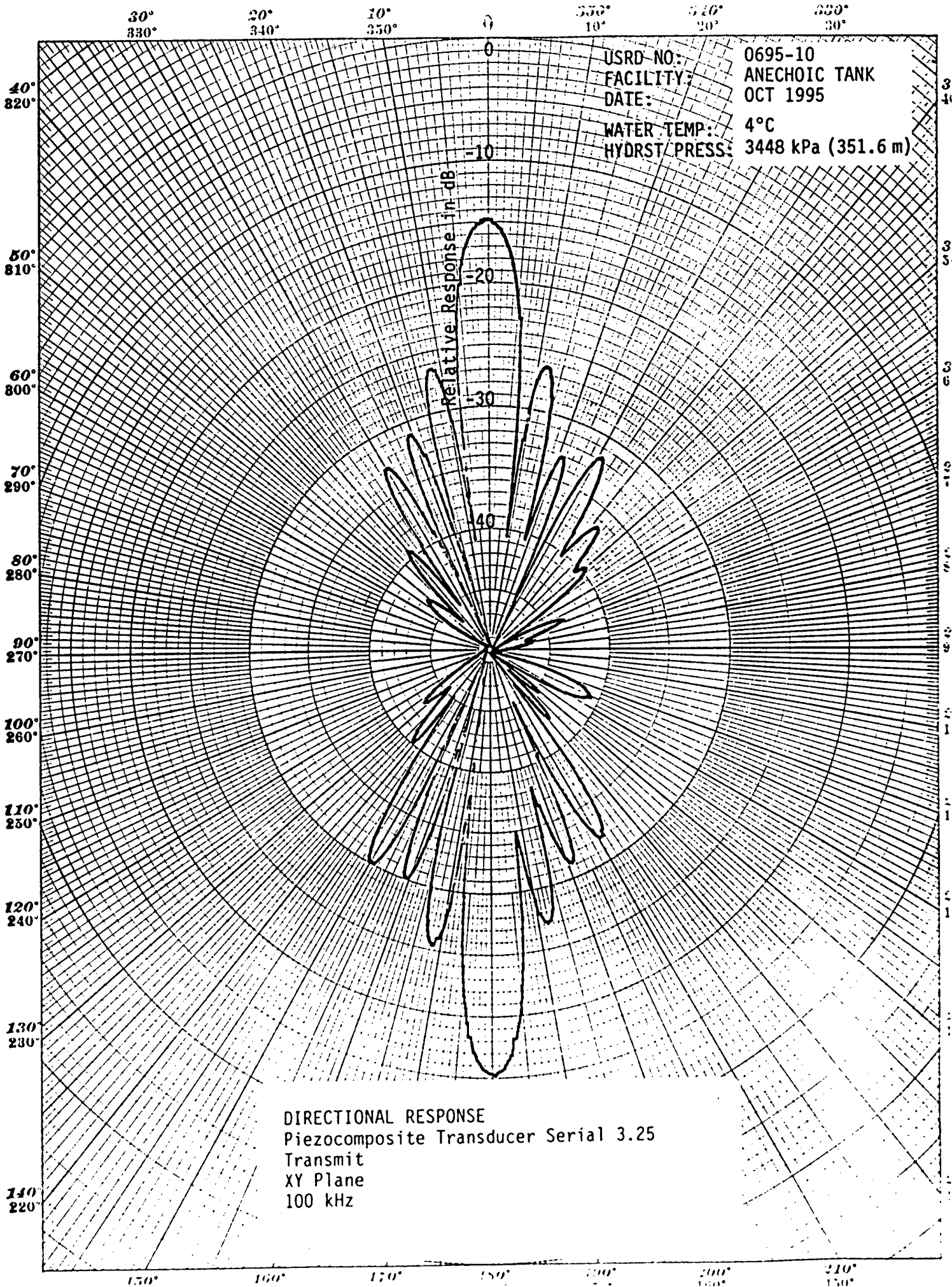
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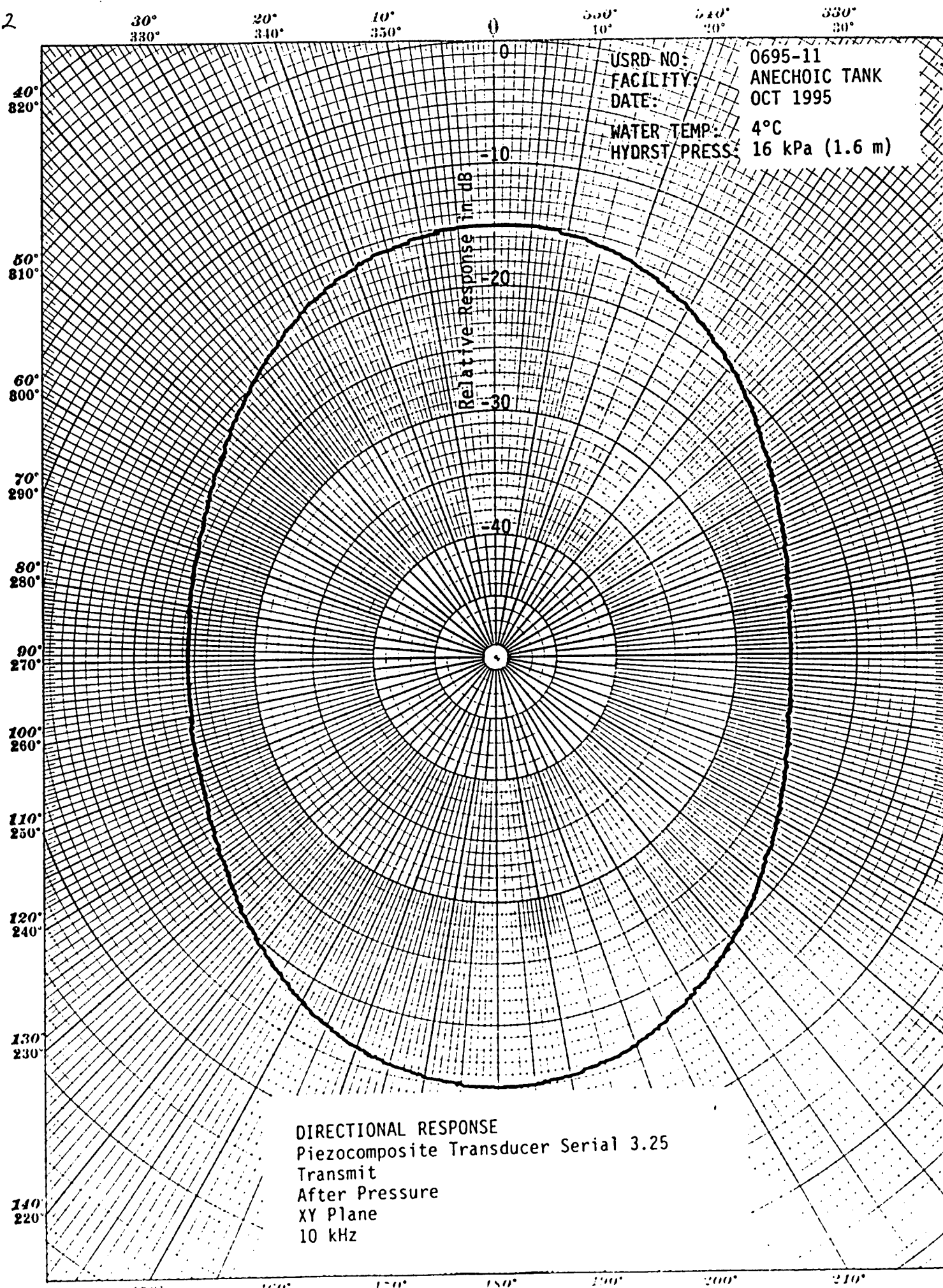
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
XY Plane  
10 kHz

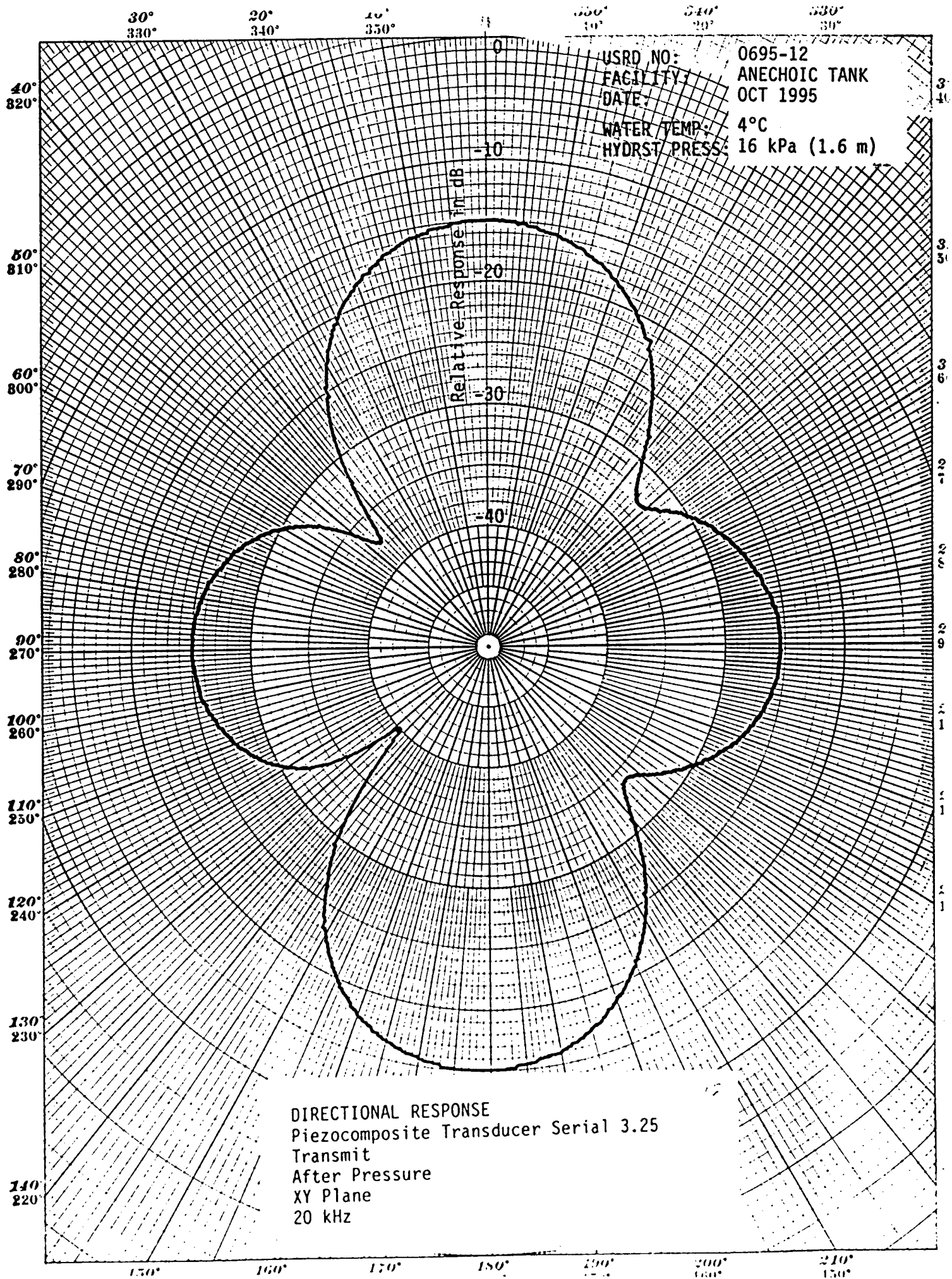




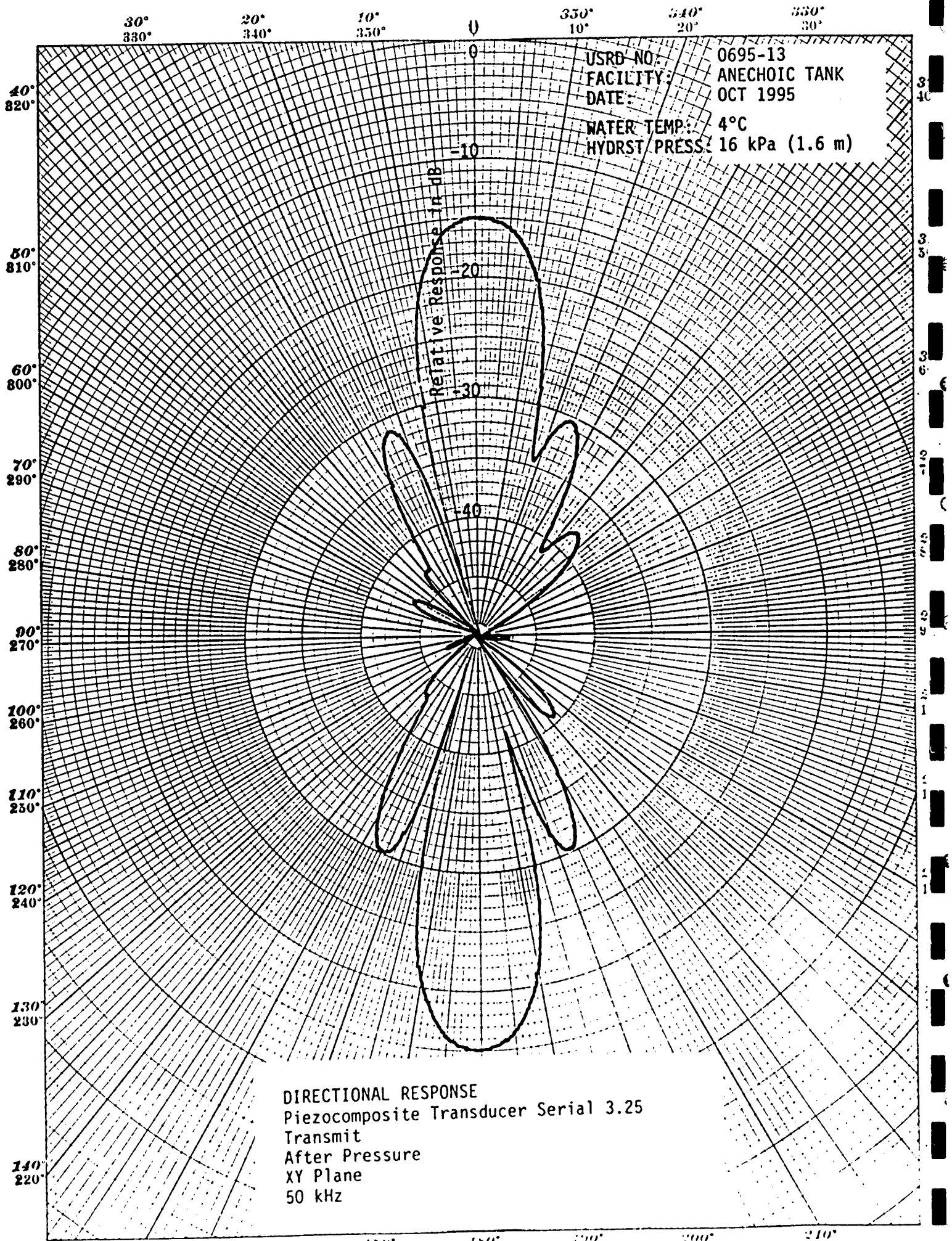


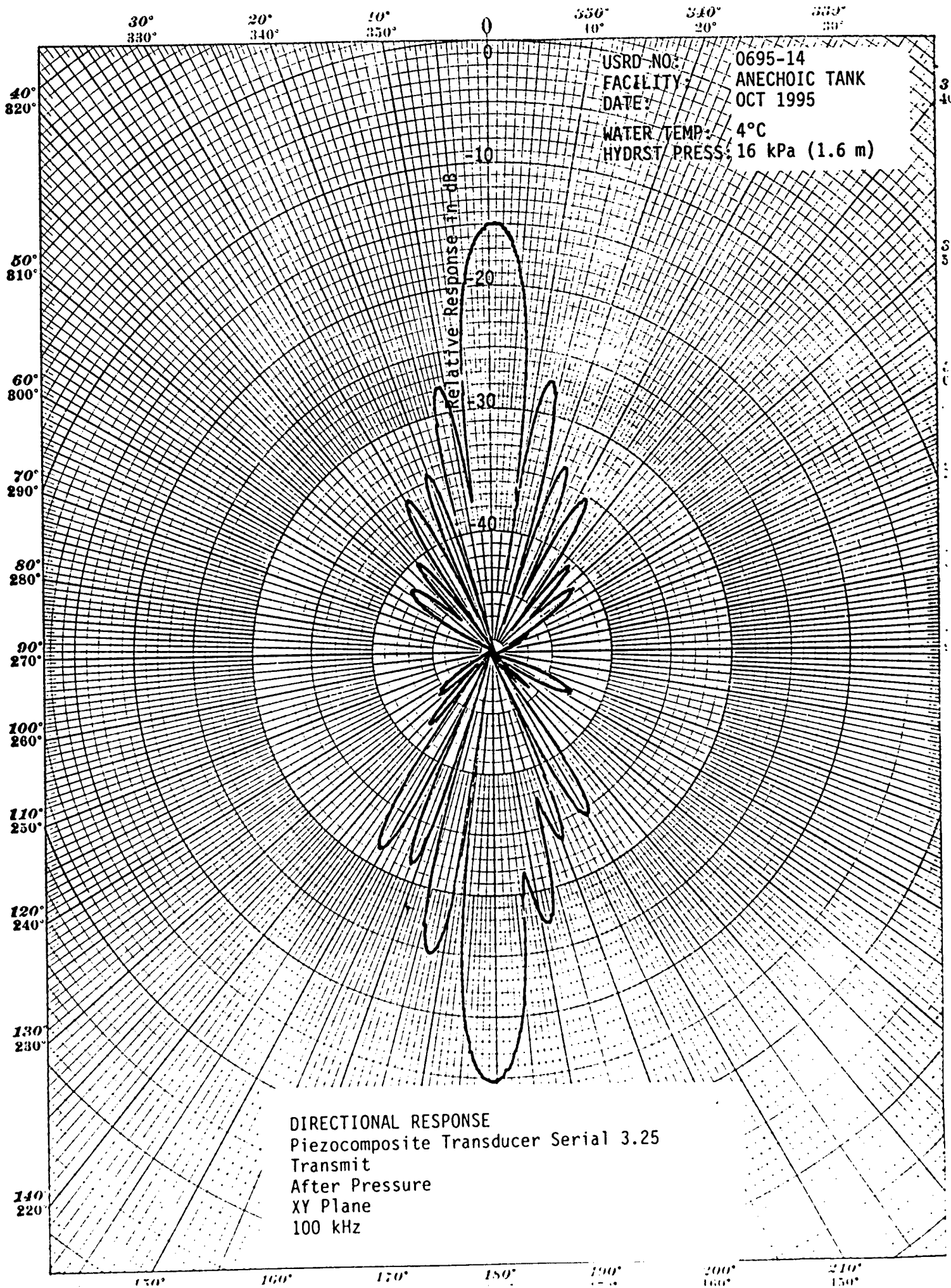














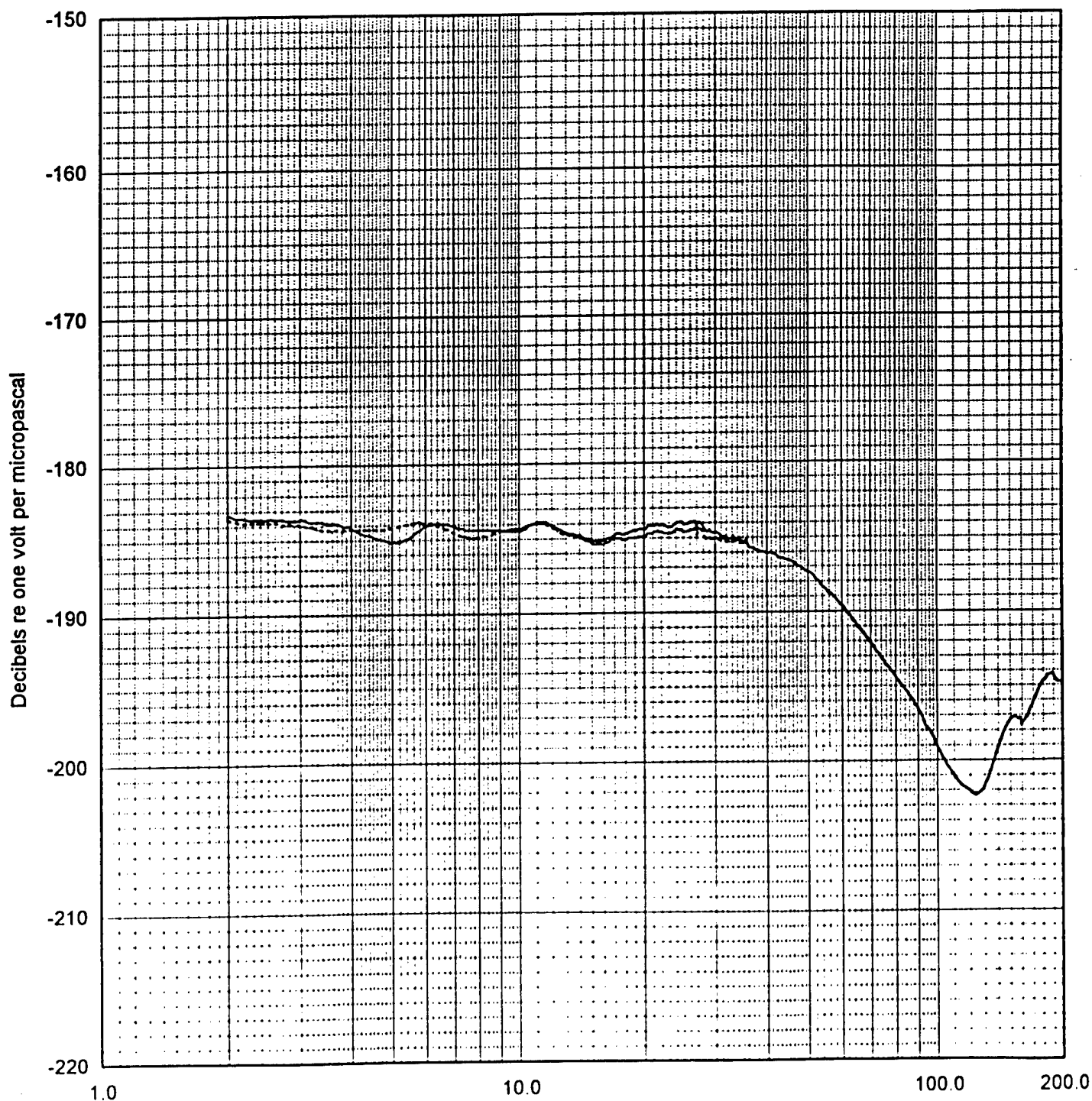
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 3.25

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa (1.6 m) Before Pressure  
----- 16 kPa (1.6 m) After Pressure



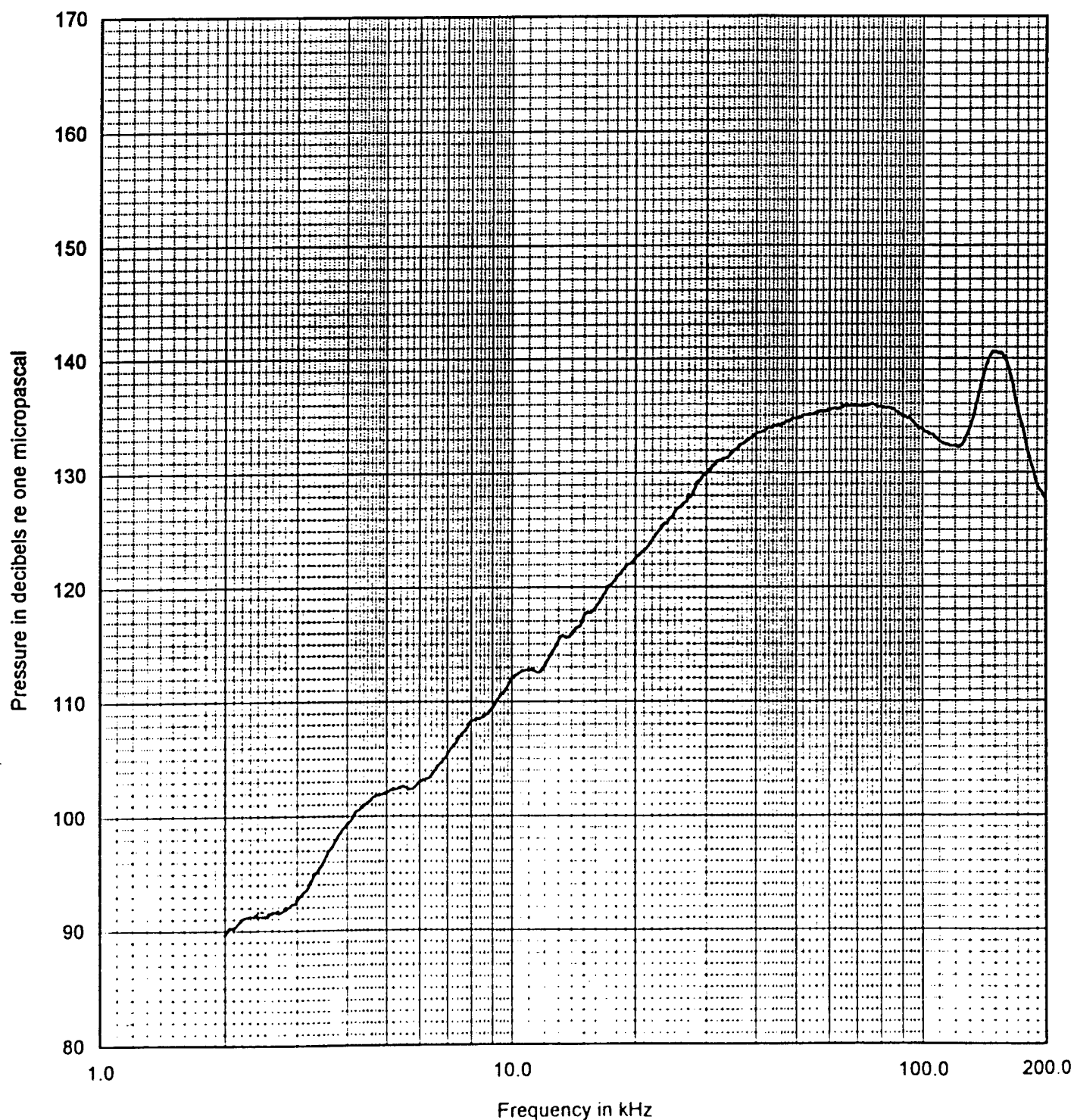
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 3.25

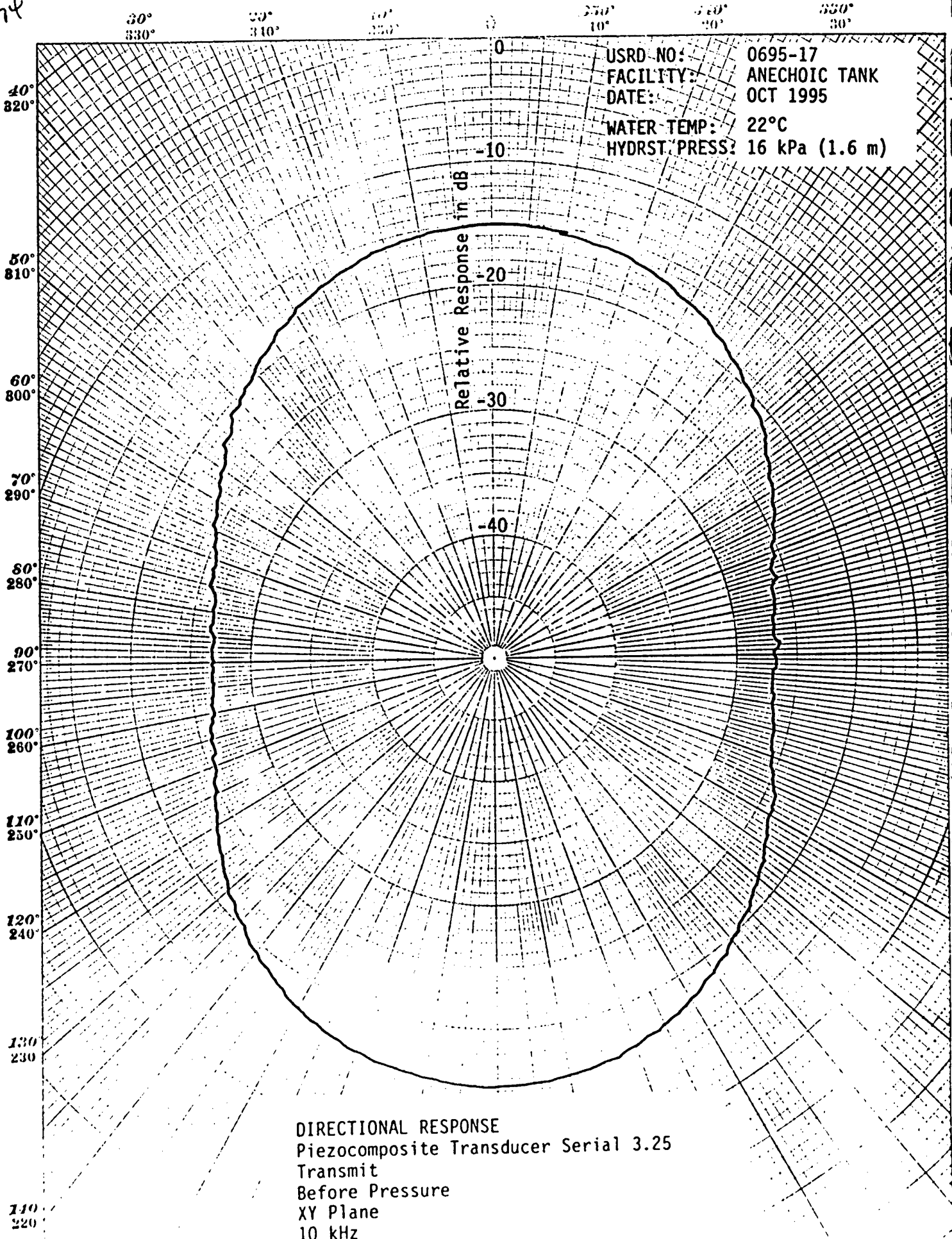
Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

— 16 kPa (1.6 m) Before Pressure  
- - - 16 kPa (1.6 m) After Pressure



74



USRD NO: 0695-17  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
Before Pressure  
XY Plane  
10 kHz

13

30°  
330°30°  
330°30°  
330°30°  
330°30°  
330°30°  
330°40°  
320°50°  
310°60°  
300°70°  
290°80°  
280°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°

Relative Response in dB

-10

-20

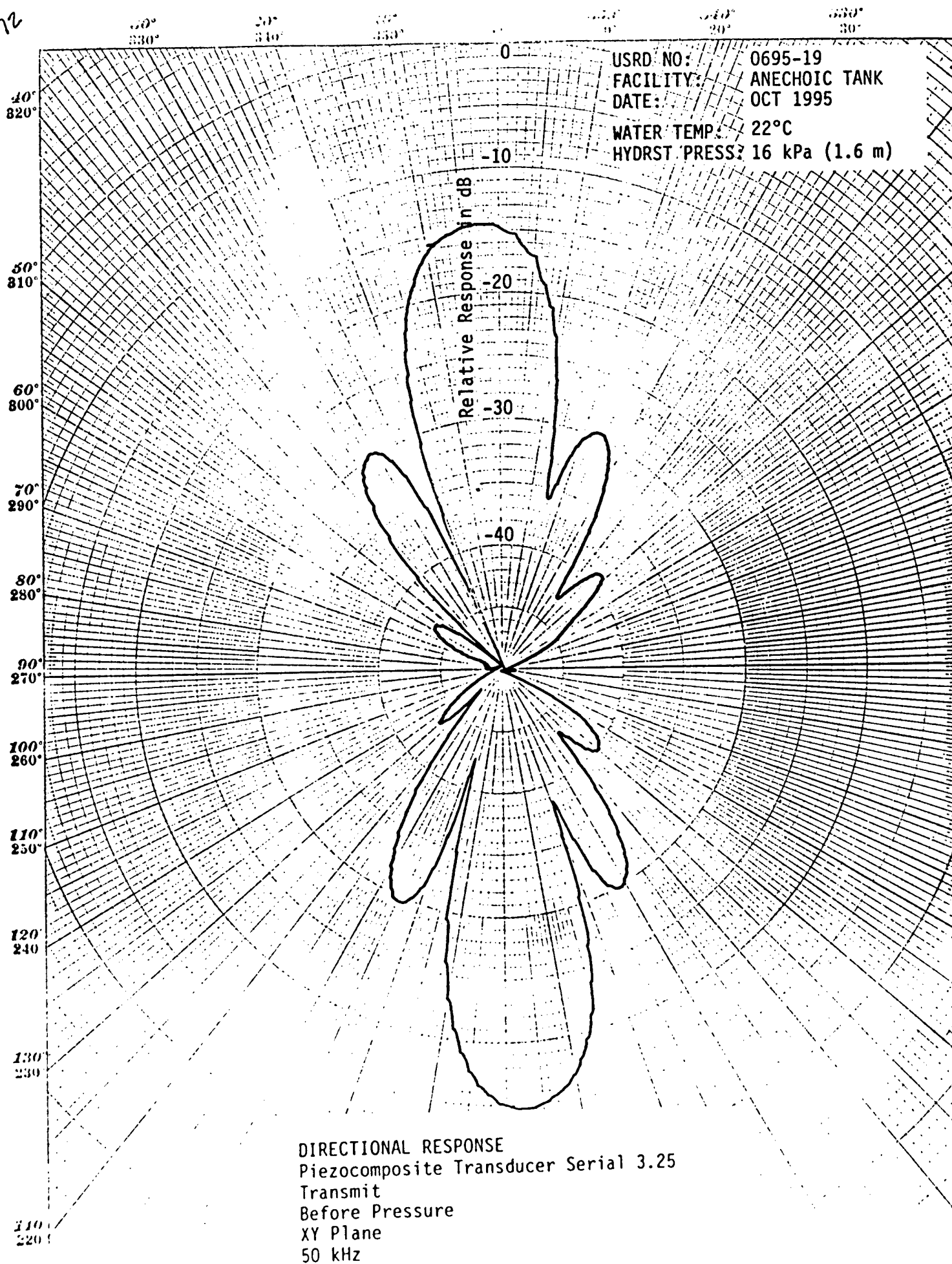
-30

-40

USRD NO: 0695-18  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
Before Pressure  
XY Plane  
20 kHz

72





71

330° 340° 350° 0° 10° 20° 330° 30°

USRD NO: 0695-20  
 FACILITY: ANECHOIC TANK  
 DATE: OCT 1995  
 WATER TEMP: 22°C  
 HYDRST PRESS: 16 kPa (1.6 m)

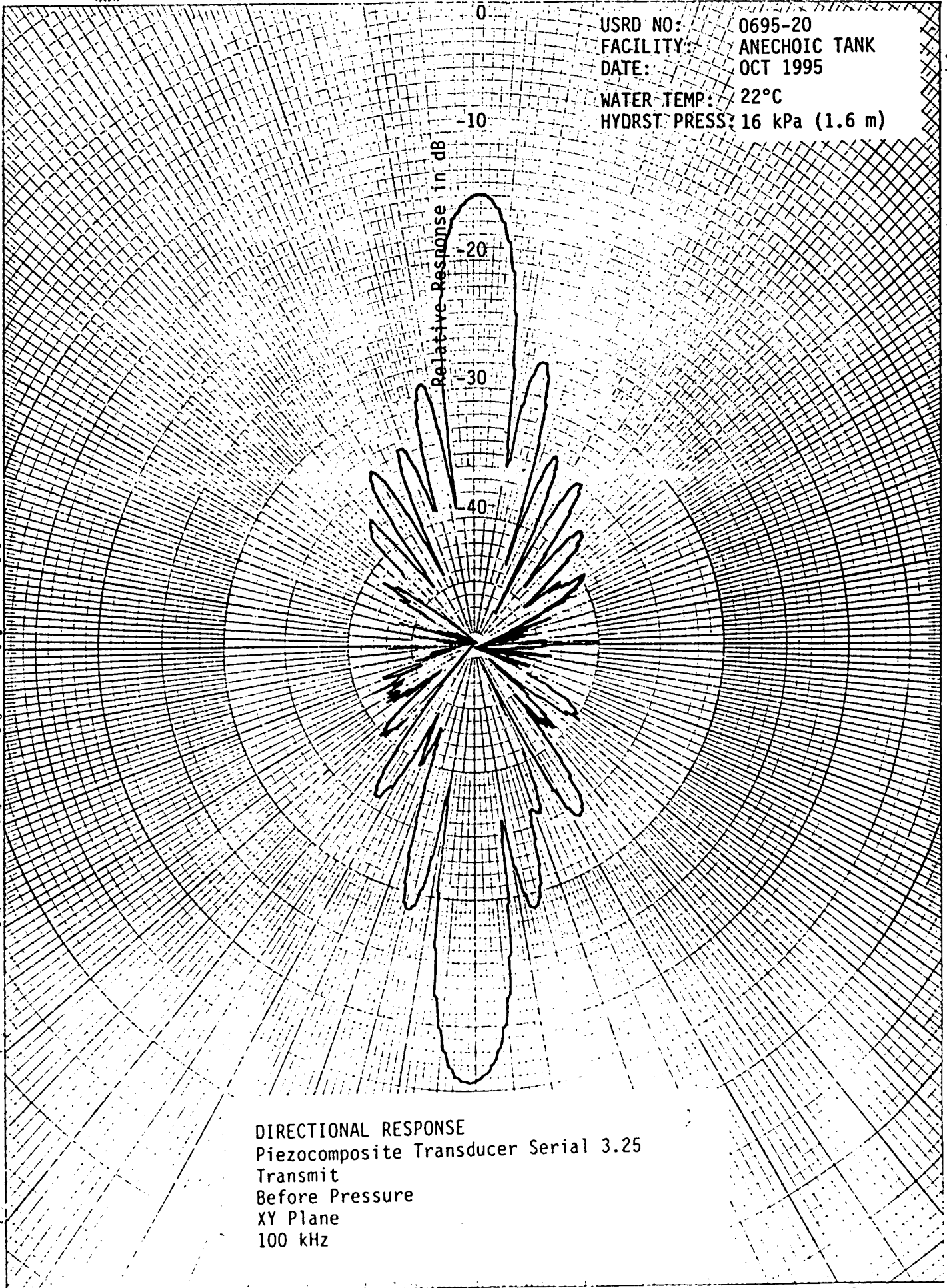
40° 820°  
 50° 810°  
 60° 800°  
 70° 290°  
 80° 280°  
 90° 270°  
 100° 260°  
 110° 250°  
 120° 240°  
 130° 230°  
 140° 220°

Relative Response in dB

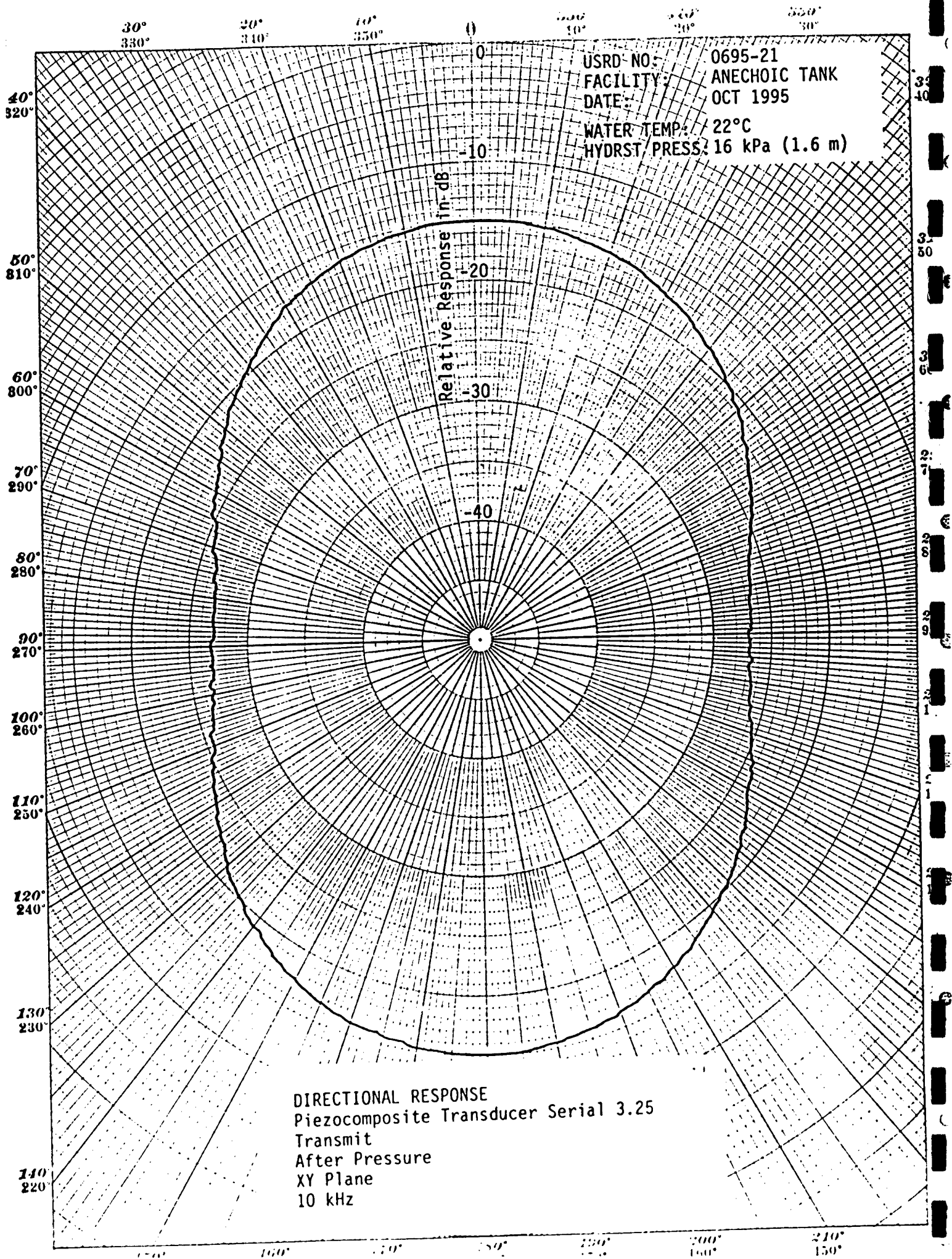
0  
 -10  
 -20  
 -30  
 -40

DIRECTIONAL RESPONSE  
 Piezocomposite Transducer Serial 3.25  
 Transmit  
 Before Pressure  
 XY Plane  
 100 kHz

150° 160° 170° 180° 190° 200° 210°  
 160° 170°





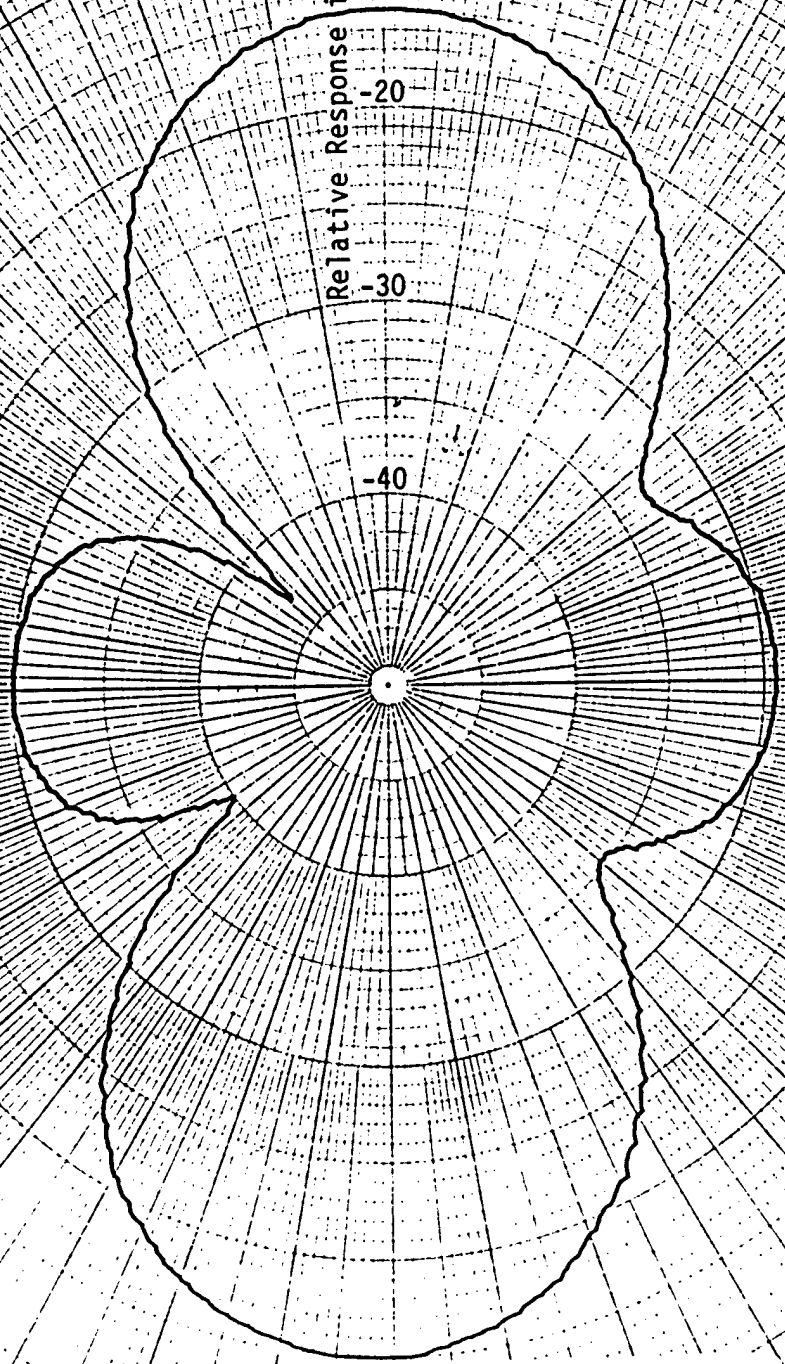


74

30° 20° 10° 0° 330° 340° 350° 360° 370° 380° 390° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140°

USRD NO: 0695-22  
 FACILITY: ANECHOIC TANK  
 DATE: OCT 1995  
 WATER TEMP: 22°C  
 HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB



DIRECTIONAL RESPONSE  
 Piezocomposite Transducer Serial 3.25  
 Transmit  
 After Pressure  
 XY Plane  
 20 kHz

30°  
330°

20°  
340°

10°  
350°

0°

300°  
10°

240°  
20°

330°  
30°

USRD NO: 0695-23  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
After Pressure  
XY Plane  
50 kHz

46

30°  
330°20°  
310°10°  
300°

0°

350°  
10°340°  
20°330°  
30°40°  
820°50°  
810°60°  
800°70°  
790°80°  
780°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°

340°

350°

360°

370°

380°

390°

400°

410°

420°

430°

440°

USRD NO: 0695-24  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0  
-10  
-20  
-30  
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 3.25  
Transmit  
After Pressure  
XY Plane  
100 kHz

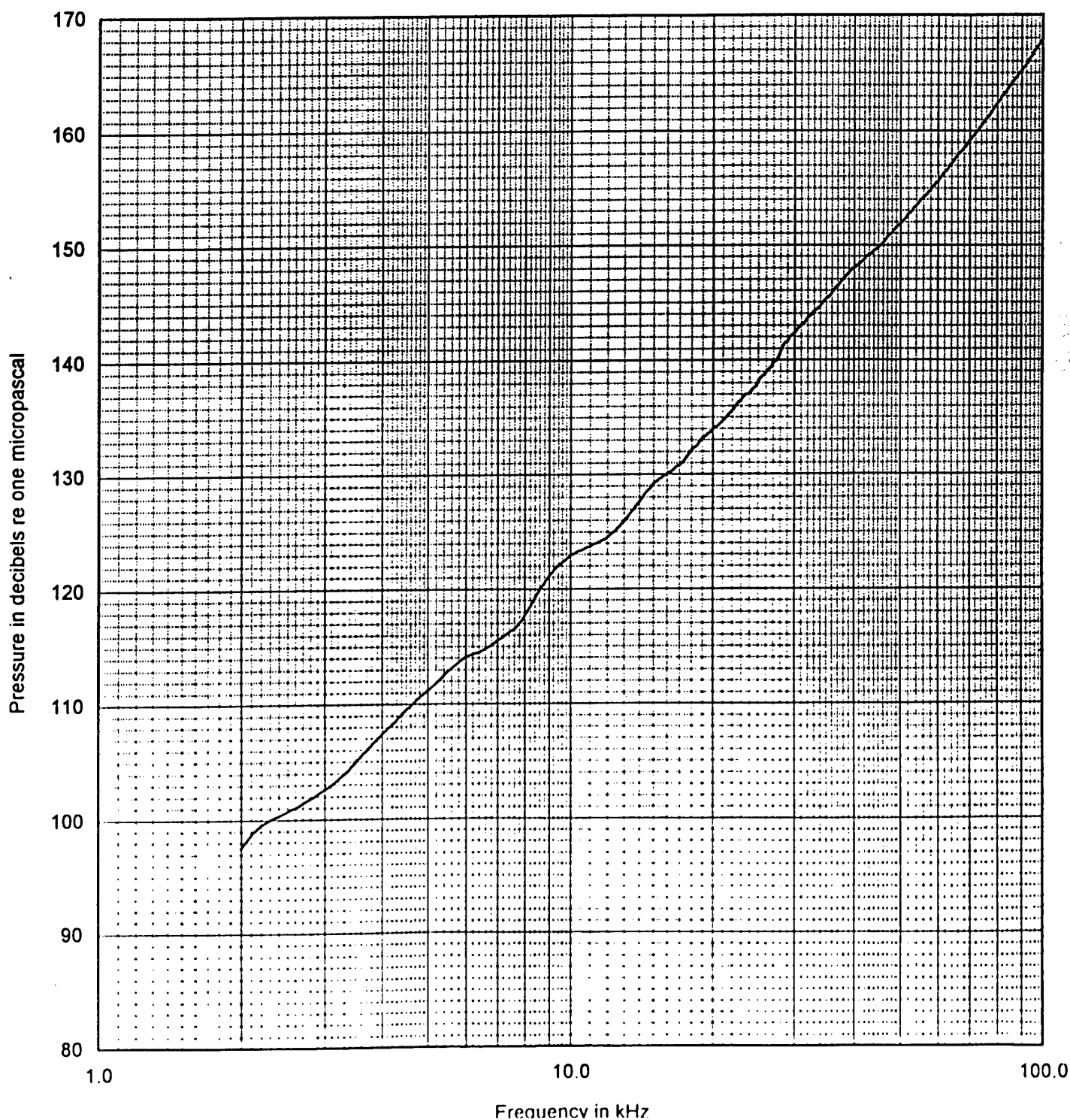
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 36S30-1

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

Hydrostatic Pressure: 16 kPa (1.6 m)





## TRANSMITTING VOLTAGE RESPONSE

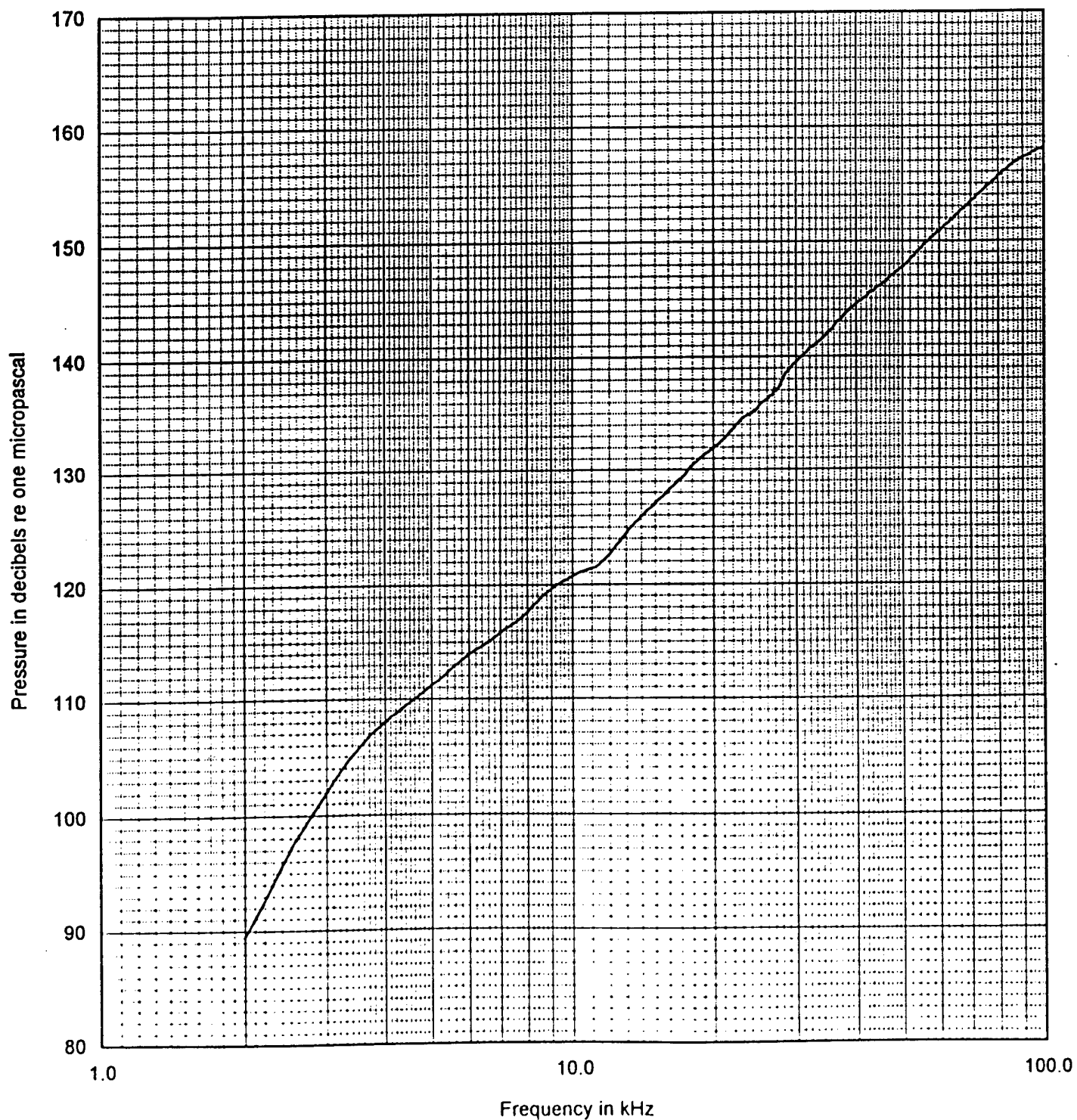
Piezocomposite Transducer Serial 36S8-2

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

Hydrostatic Pressure: 16 kPa (1.6 m)

100 VRMS drive





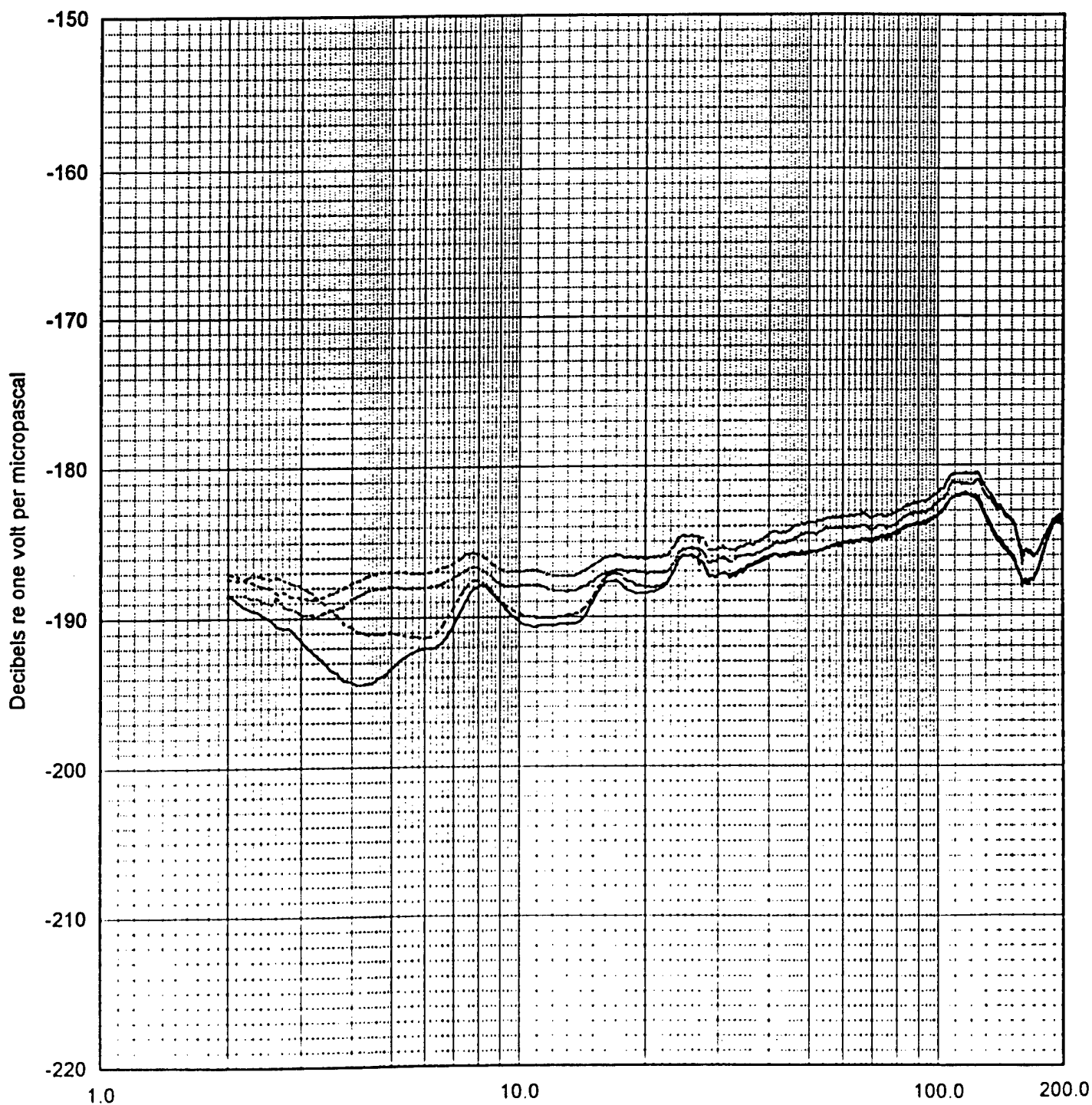
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-29

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
- . - . - 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



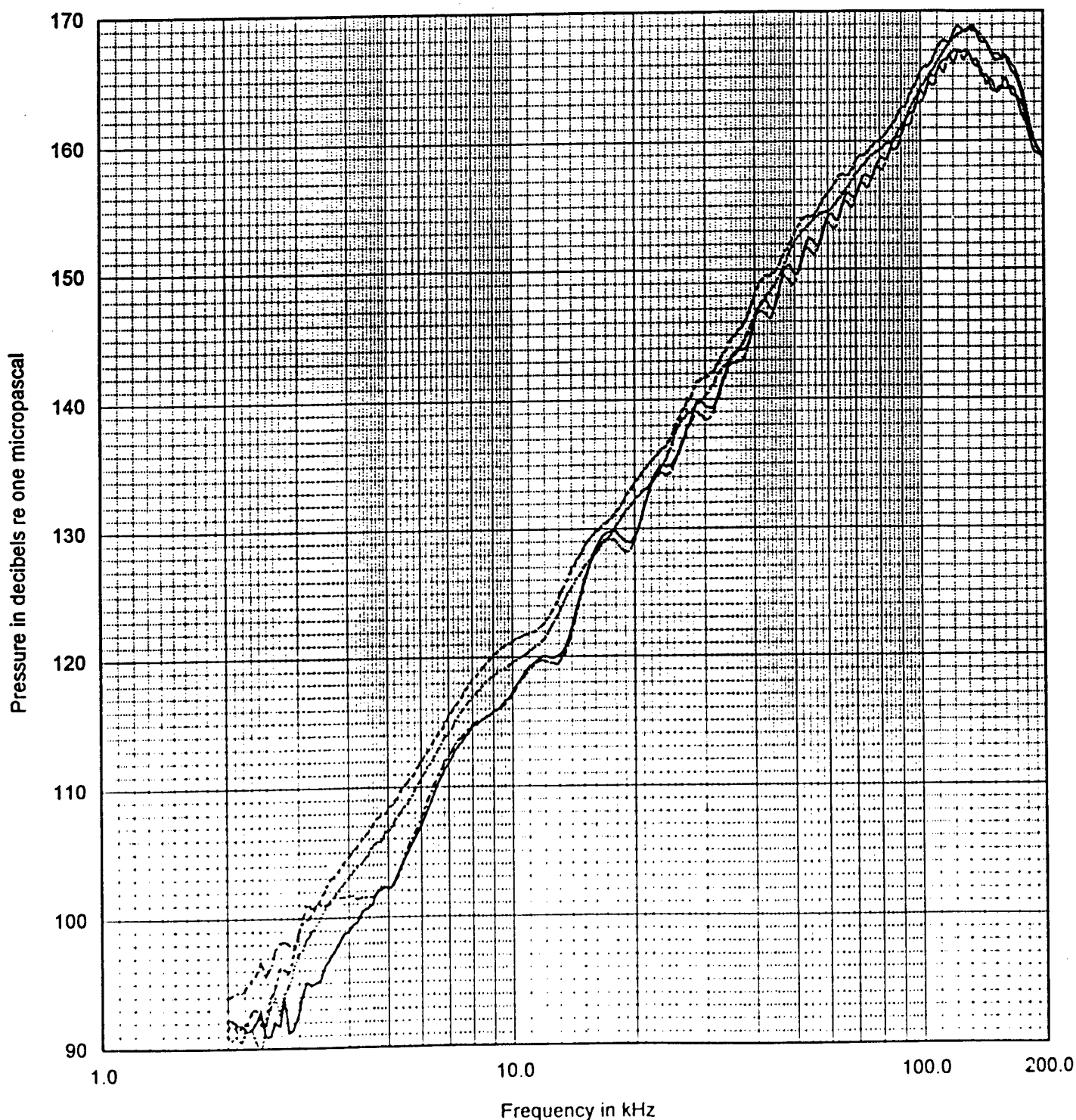
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-29

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

- 16 kPa ( 1.6 m) Before Pressure
- 3448 kPa ( 351.6 m)
- ..... 6895 kPa ( 703.1 m)
- 16 kPa ( 1.6 m) After Pressure



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-29  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in db

-10

-20

-30

-40

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

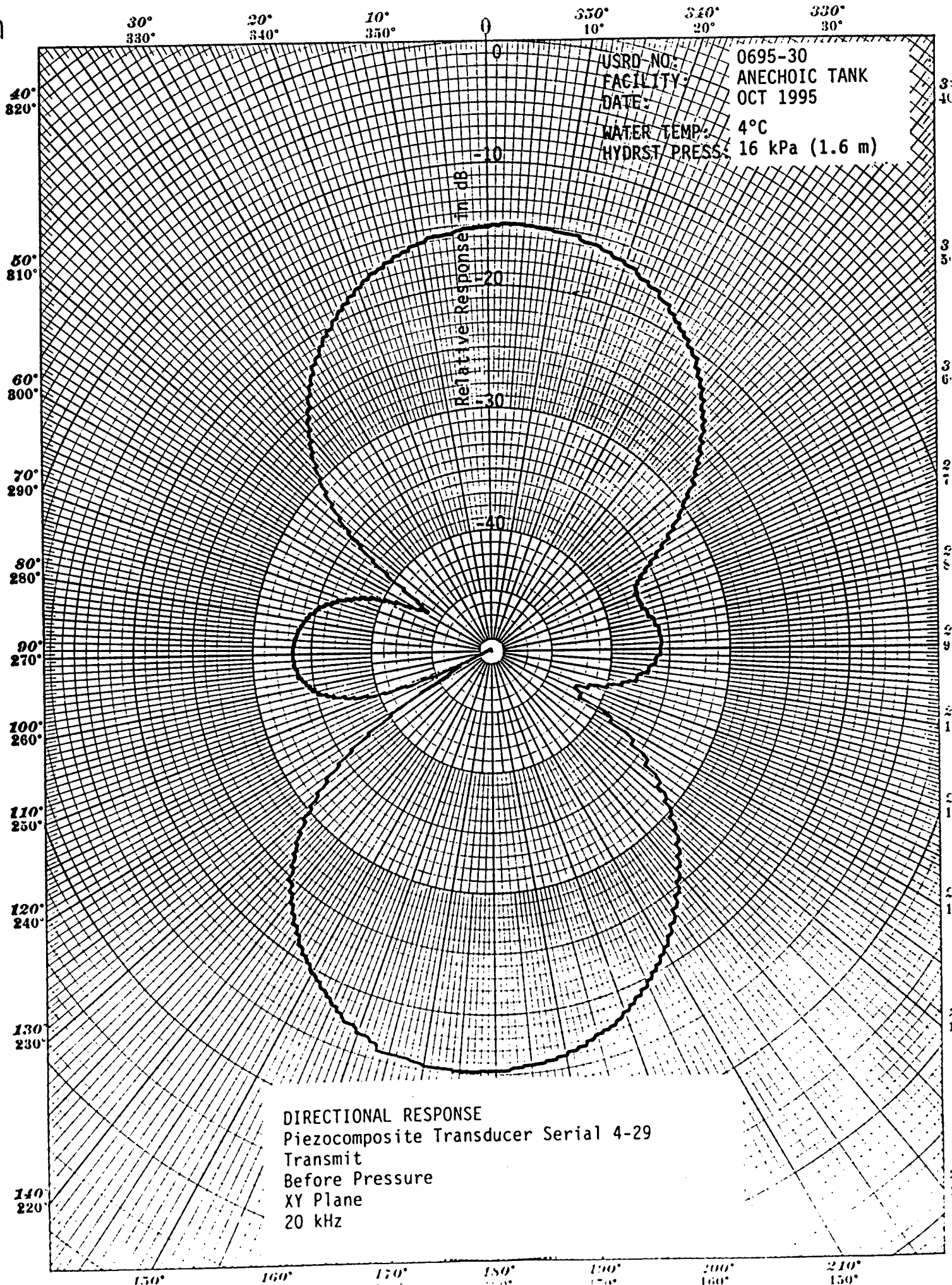
250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
Before Pressure  
XY Plane  
10 kHz





30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO:  
FACILITY:  
DATE:

0695-31  
ANECHOIC TANK  
OCT 1995

WATER TEMP: 4°C

HYDRST/PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

-20

-30

-40

-50

-60

-70

-80

-90

-100

-110

-120

-130

-140

-150

-160

-170

-180

-190

-200

-210

-220

-230

-240

-250

-260

-270

-280

-290

-300

-310

-320

-330

-340

-350

-360

-370

-380

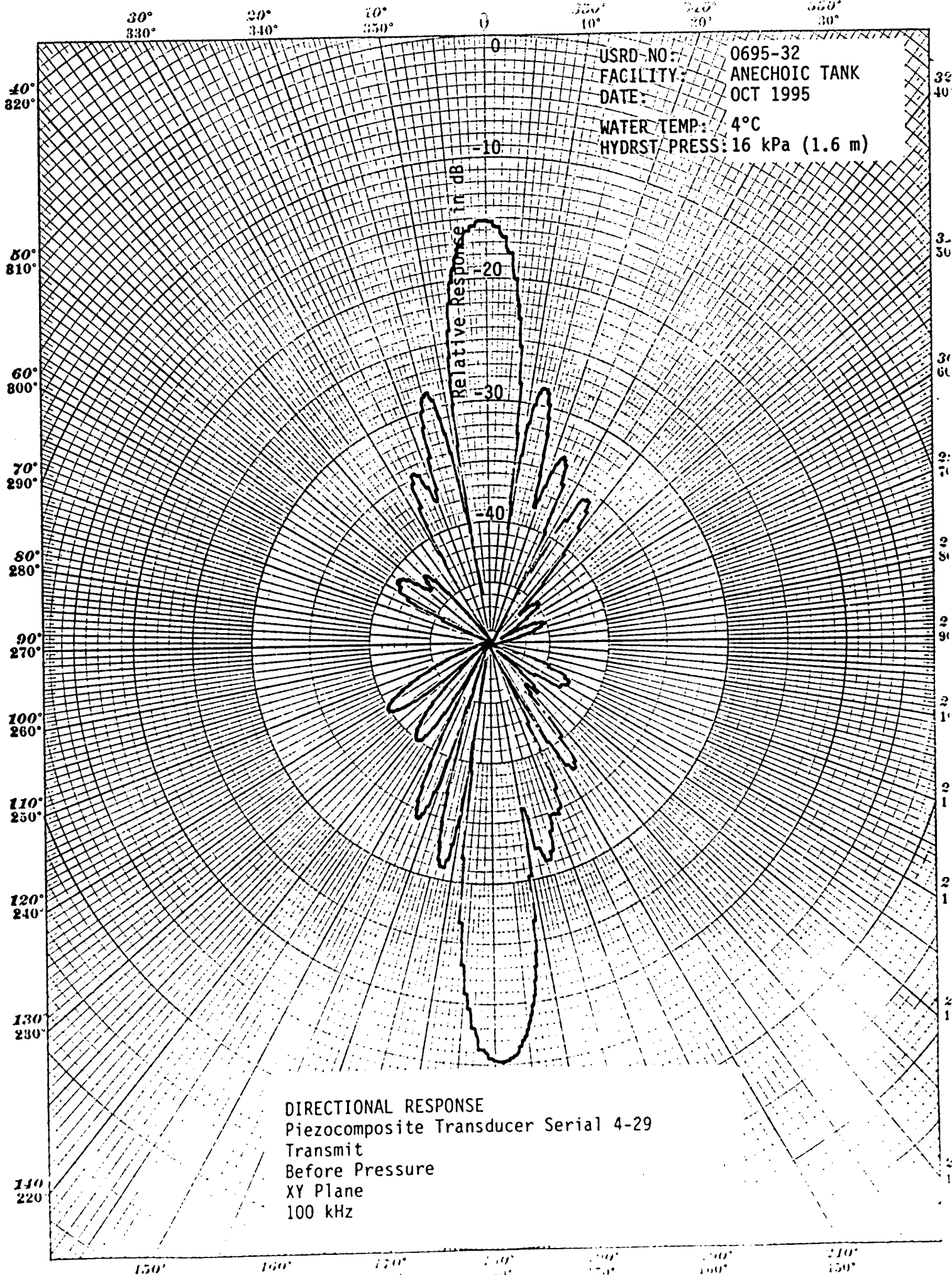
-390

-400

-410

-420

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
Before Pressure  
XY Plane  
50 kHz





30°  
330°

20°  
340°

10°  
350°

0°

330°  
10°

340°  
20°

350°  
30°

USRD NO: 0695-33  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

0

-20

-30

-40

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
10 kHz

30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 0° 10° 20° 30°

USRD NO: 0695-34  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB  
0  
-10  
-20  
-30  
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
20 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-35  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
50 kHz

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

30°  
330°

20°  
340°

10°  
350°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-36  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
100 kHz



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-37  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

0

-10

-20

-30

-40

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
10 kHz

5

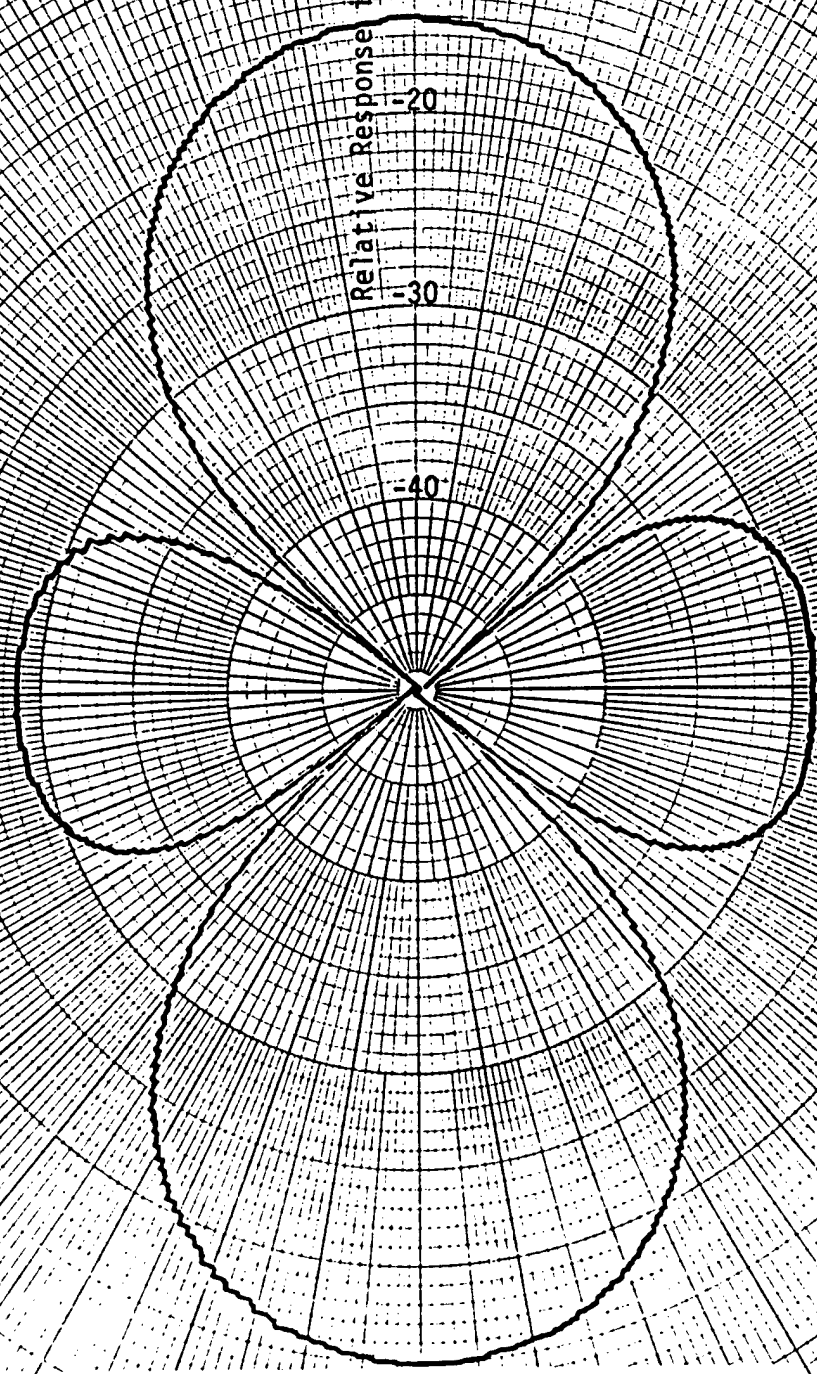
30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD-NO: 0695-38  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

40° 820°  
50° 810°  
60° 800°  
70° 290°  
80° 280°  
90° 270°  
100° 260°  
110° 250°  
120° 240°  
130° 230°  
140° 220°

30°  
40°  
50°  
60°  
70°  
80°  
90°  
100°  
110°  
120°  
130°  
140°

Relative Response in dB  
0  
-10  
-20  
-30  
-40



DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
20 kHz



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

220°  
20°

550°  
30°

USRD NO: 0695-39  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-40  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST/PRESS: 6895 kPa (703.1 m)

Relative Response in dB

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
100 kHz

150°

160°

170°

180°

190°

200°

210°

150°

30°  
330°

20°  
340°

10°  
350°

0°

330°  
10°

340°  
20°

350°  
30°

USRD NO: 0695-41  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
After Pressure  
XY Plane  
10 kHz

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
10°

250°  
11°

240°  
12°

230°  
13°

220°  
14°

210°  
15°

200°  
16°

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

USRD NO: 0695-42  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST/ PRESS: 16 kPa (1.6 m)

Relative Response in db

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
After Pressure  
XY Plane  
20 kHz

150°

160°

170°

180°

190°

200°  
160°

210°  
150°



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-43  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
After Pressure  
XY Plane  
50 kHz

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

30°  
330°

20°  
340°

10°  
350°

0°  
10°

330°  
20°

30°  
30°

USRD NO: 0695-44  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative response in dB

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
After Pressure  
XY Plane  
100 kHz

150°

160°

170°

180°

190°

200°

210°

150°



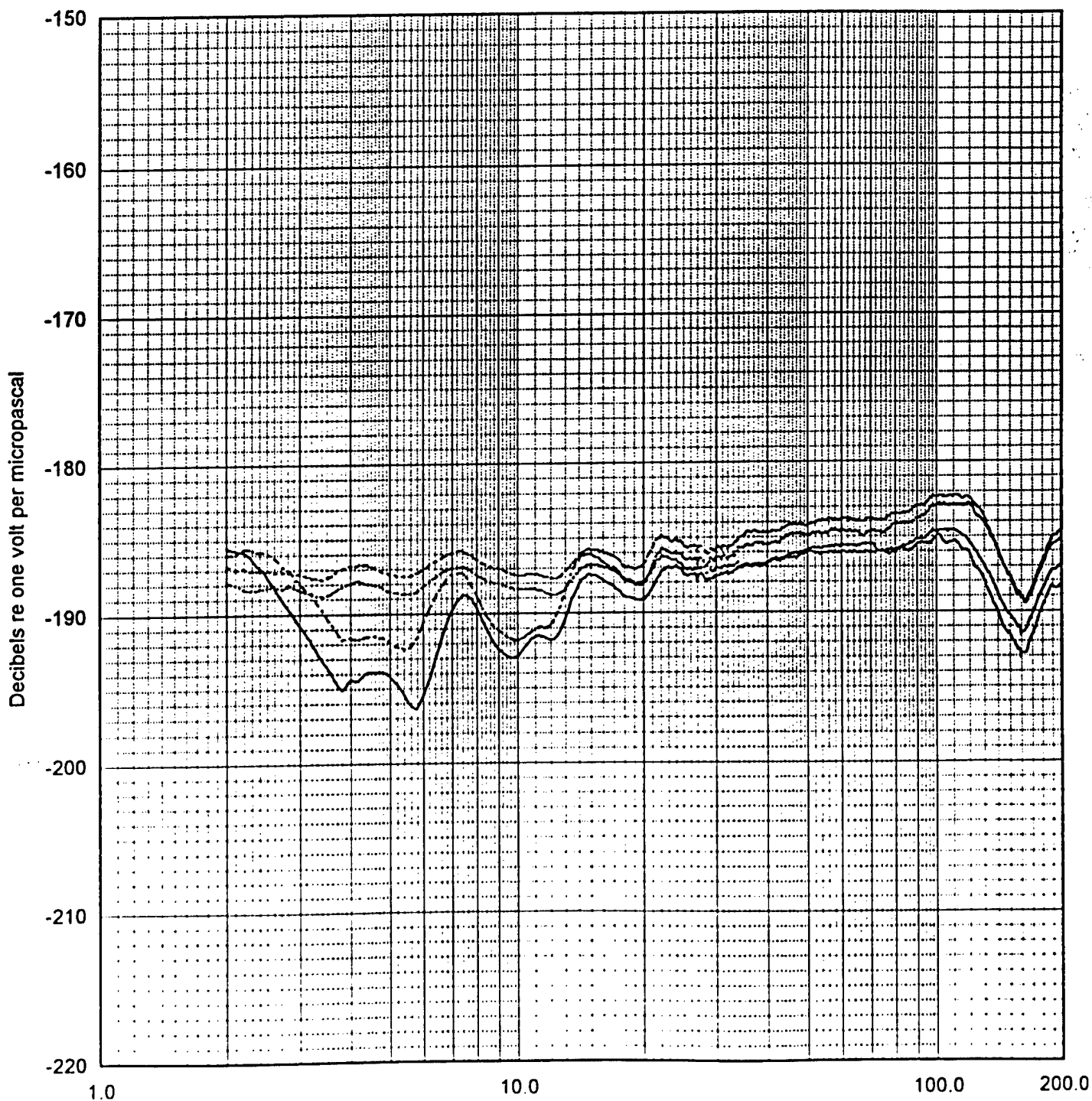
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-29

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



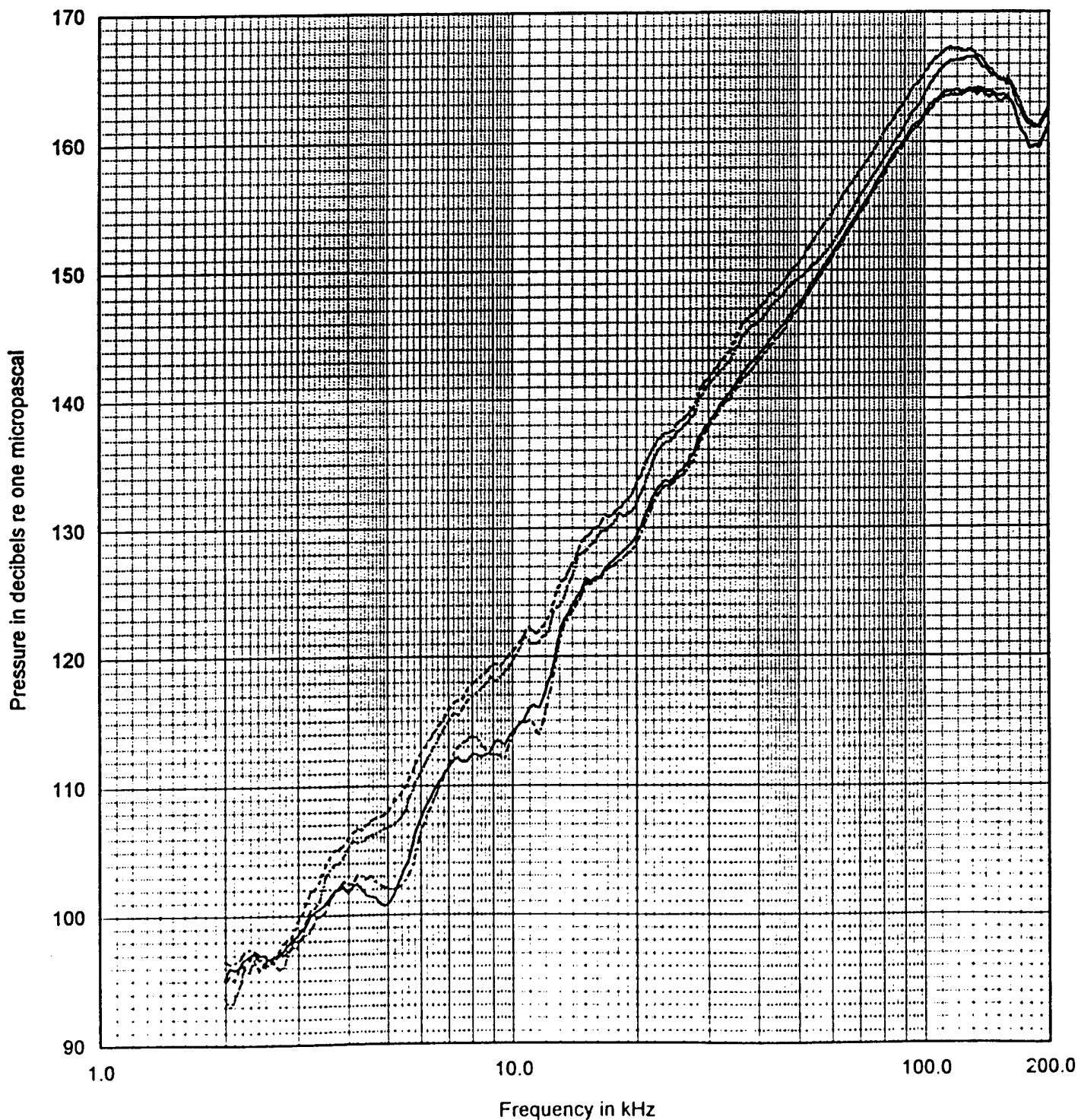
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-29

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
- - - - - 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



30°  
330°

20°  
340°

10°  
350°

0°

330°  
10°

310°  
20°

330°  
30°

USRD NO: 0695-47  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0  
-10  
-20  
-30  
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
Before Pressure  
XY Plane  
10 kHz

330  
30  
360

34  
40



36

212

625

912

— 29 —

11

100

Final

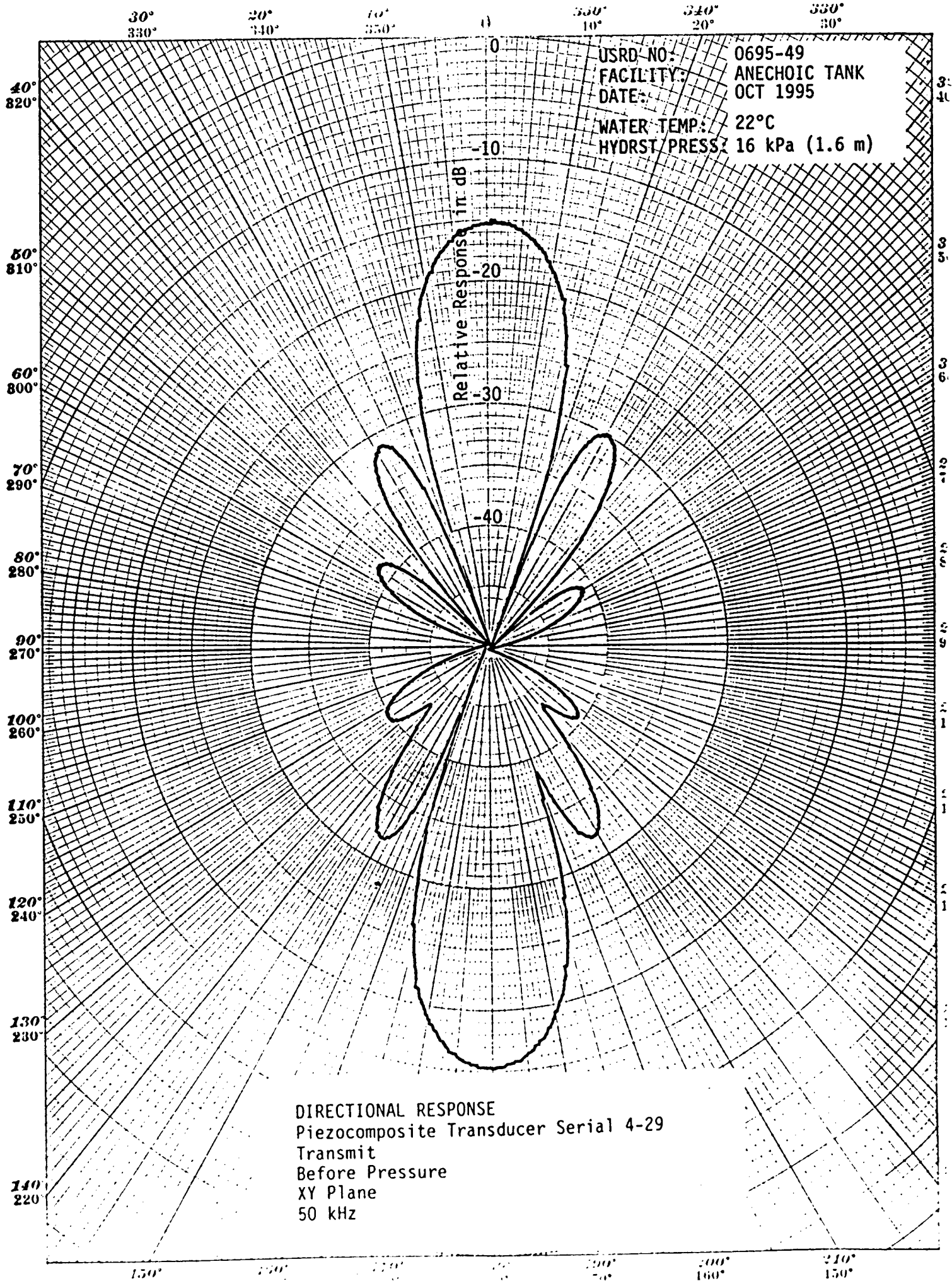
•

778

...

iii)

150°





30°  
330°

20°  
340°

10°  
350°

0°

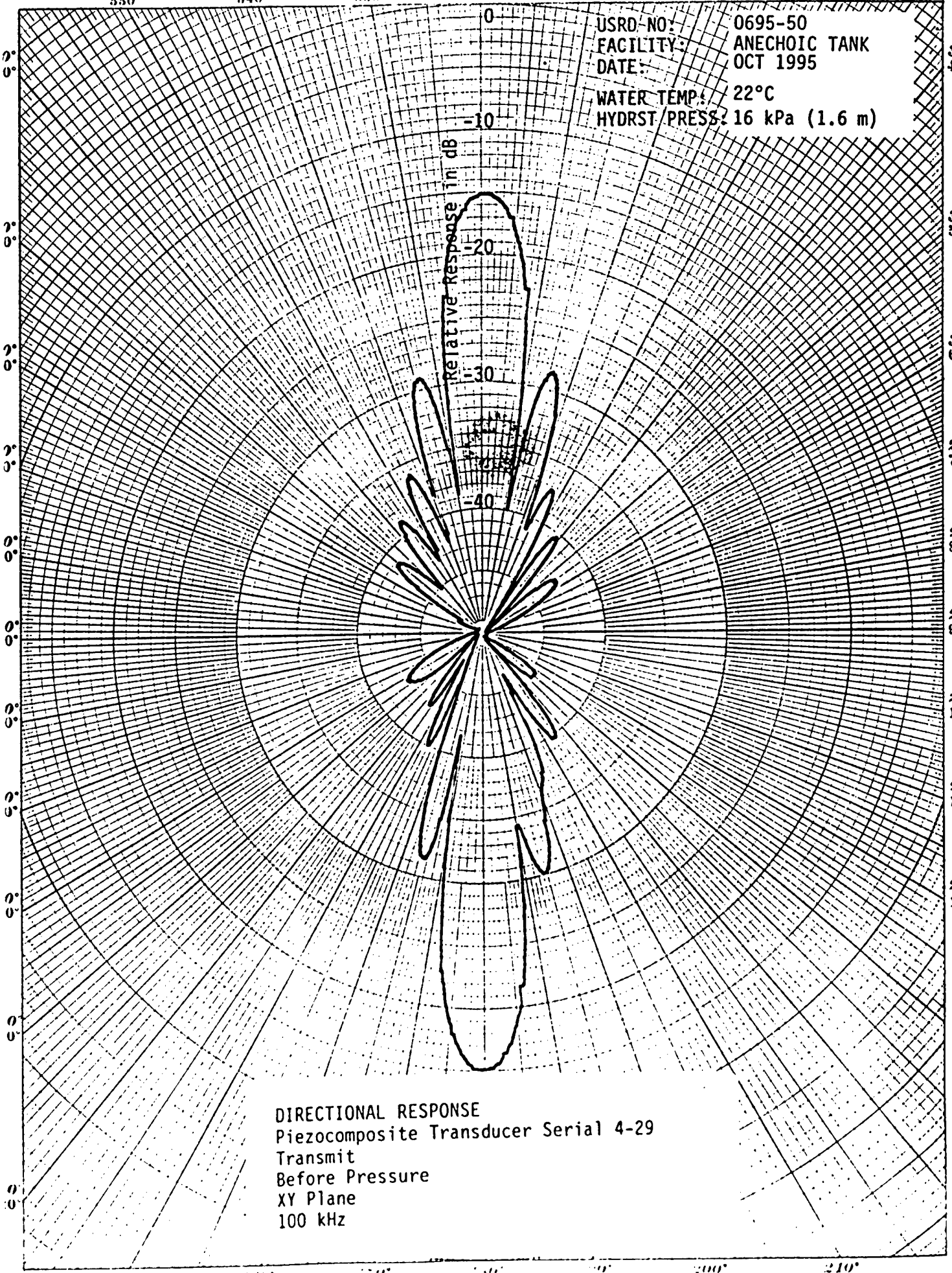
350°  
10°

340°  
20°

330°  
30°

USRD-NO: 0695-50  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 16 kPa (1.6 m)

Relative Response in dB



32  
40

31  
50

30  
60

29  
70

28  
80

27  
90

26  
10

25  
11

24  
12

23  
1

22  
1

21  
1

20  
1



19

30° 330° 30° 340° 10° 350° 0° 360° 10° 20° 340° 30° 330°

USRD-NO: 0695-51  
 FACILITY: ANECHOIC TANK  
 DATE: OCT 1995  
 WATER TEMP: 22°C  
 HYDRST/PRESS: 3448 kPa (351.6 m)

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB  
 0  
 -10  
 -20  
 -30  
 -40

DIRECTIONAL RESPONSE  
 Piezocomposite Transducer Serial 4-29  
 Transmit  
 XY Plane  
 10 kHz

150° 160° 170° 180° 190° 200° 210° 150°

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-52  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

0

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
20 kHz

30°  
330°

60°  
300°

90°  
270°

0°

120°  
240°

150°  
210°

180°  
180°

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

USRD NO: 0695-53  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 3448 kPa (351.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

240°  
20°

330°  
30°

USRD NO: 0695-54  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 3448 kPa (351.6 m)

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
10°

250°  
11°

240°  
12°

230°  
1°

220°  
1°

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
100 kHz

150°

160°

170°

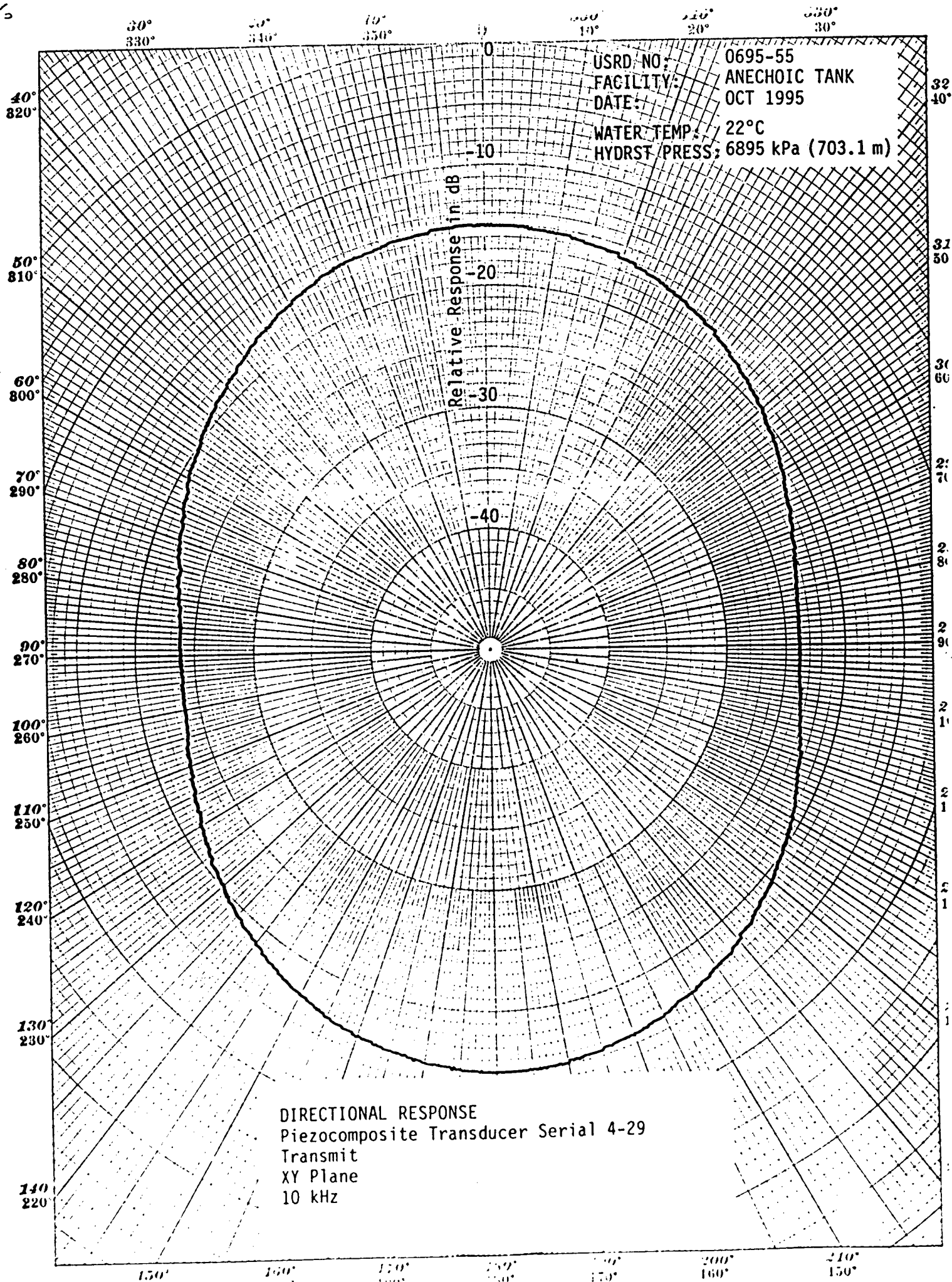
180°

190°  
170°

200°  
160°

210°  
150°





30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO:  
FACILITY:  
DATE:

0695-56  
ANECHOIC TANK  
OCT 1995

WATER TEMP: 22°C

HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

-10

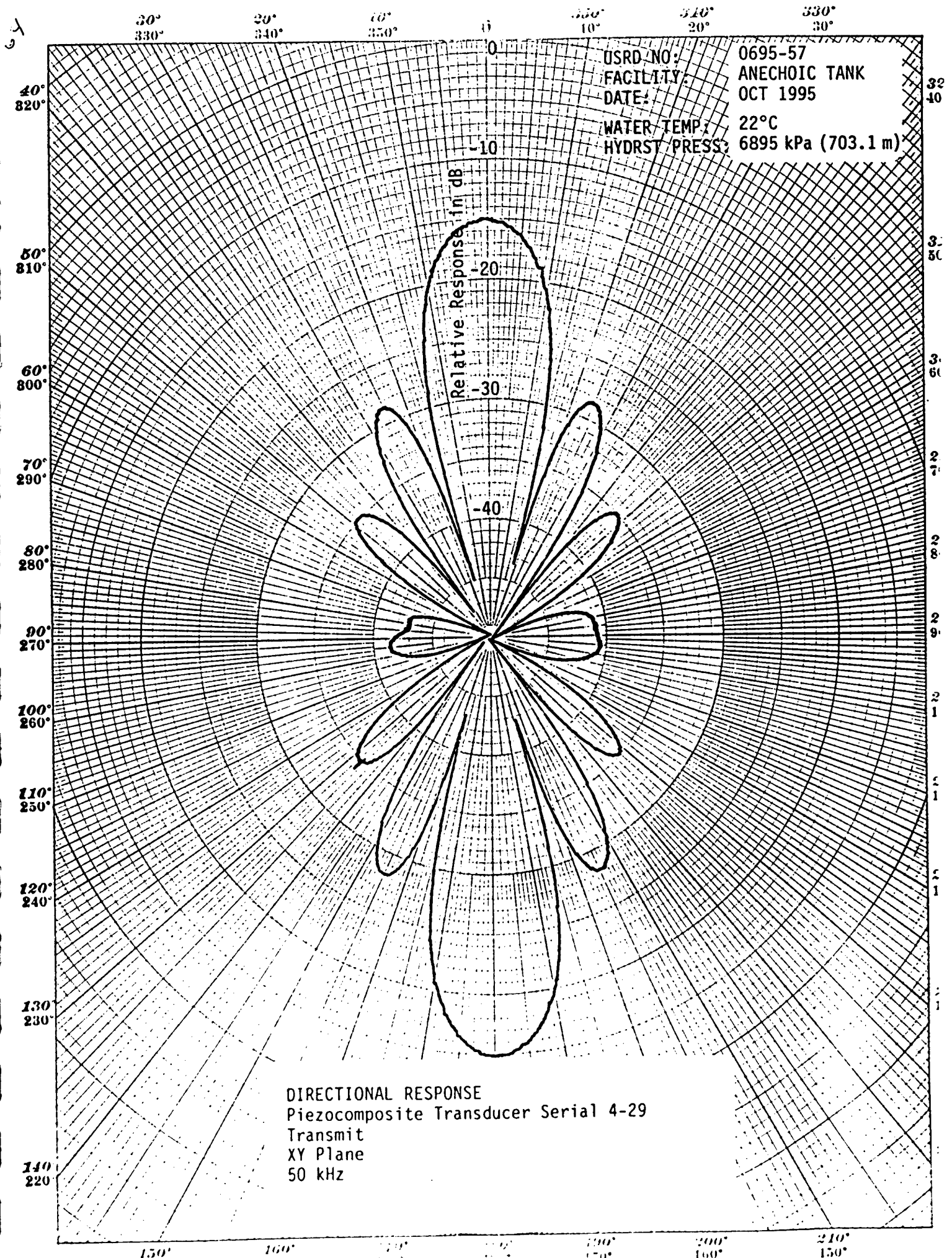
-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
20 kHz





30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO:  
FACILITY:  
DATE:

0695-58  
ANECHOIC TANK  
OCT 1995

WATER TEMP:

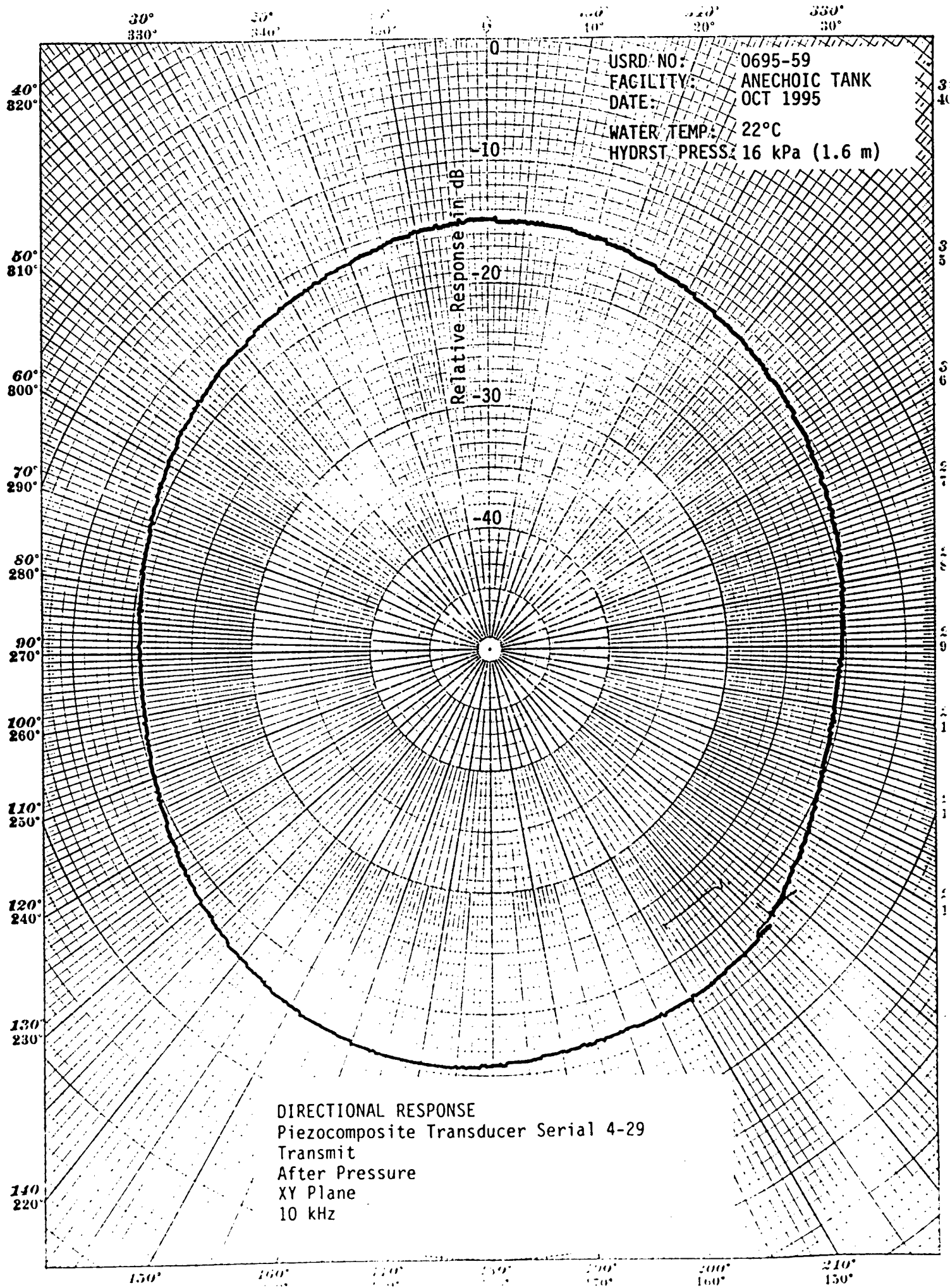
22°C

HYDRST PRESS:

6895 kPa (703.1 m)

Relative response in dB

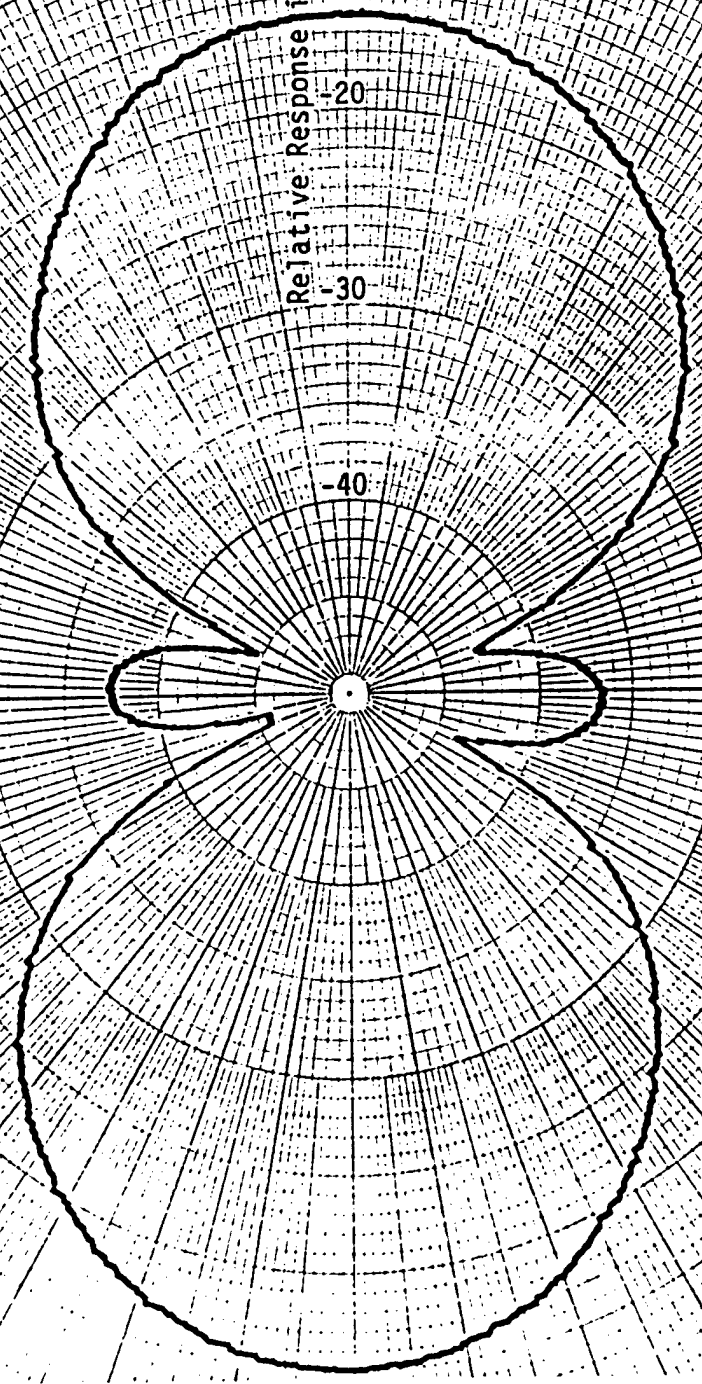
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
XY Plane  
100 kHz



30° 330° 50° 340° 10° 350° 0 360° 10° 210° 20° 330° 30°

USRD NO: 0695-60  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB



DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
After Pressure  
XY Plane  
20 kHz

320  
40°  
310  
50°  
300  
60°  
290  
70°  
280  
80°  
270  
90°  
260  
10°  
250  
11°  
240  
12°  
230  
13°  
220  
14°  
210  
15°  
200  
16°  
190  
17°  
180  
18°  
170  
19°  
160  
20°  
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26°  
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36°  
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245°  
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USRD NO: 0695-61  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
After Pressure  
XY Plane  
50 kHz

140°  
220°

150°

160°

170°

180°

190°

200°

210°

150°

30°  
330°

20°  
340°

10°  
350°

0°

330°  
10°

240°  
20°

330°  
30°

USRD NO: 0695-62  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-29  
Transmit  
After Pressure  
XY Plane  
100 kHz

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
10°

250°  
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240°  
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230°  
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220°  
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210°  
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200°  
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190°  
17°



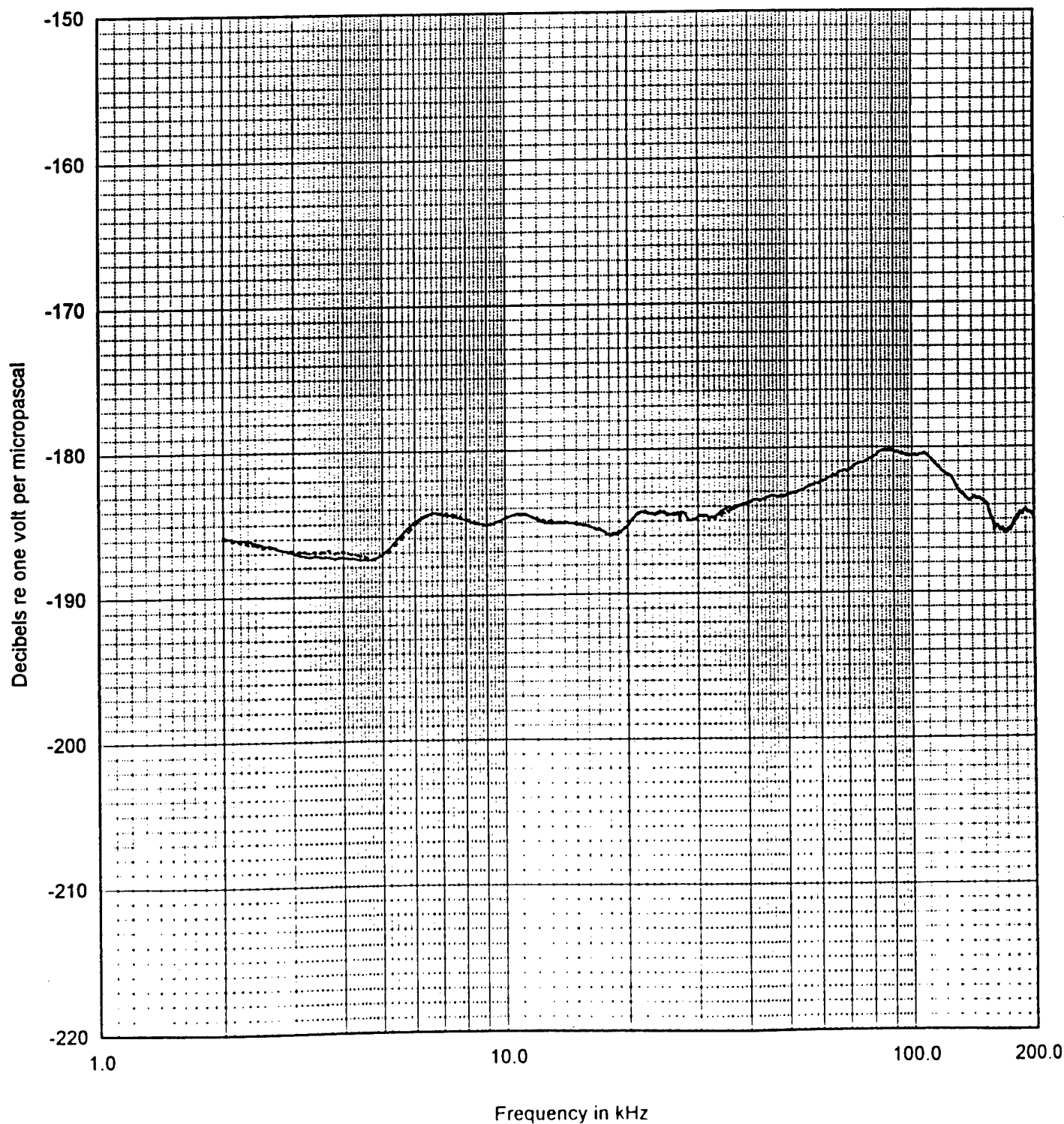
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-2P4

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

———— 16 kPa (1.6 m) Before Pressure  
----- 16 kPa (1.6 m) After Pressure



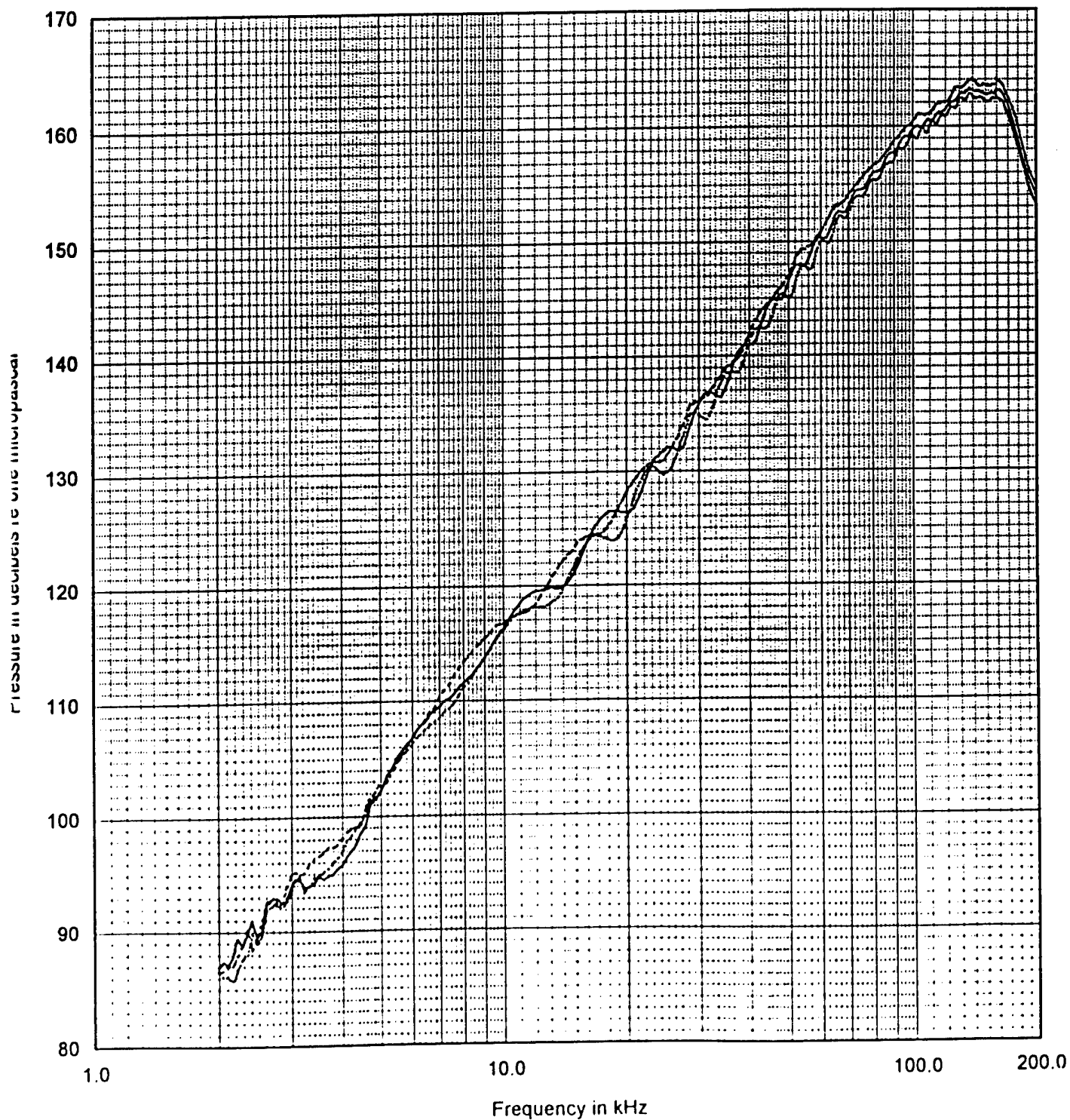
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-2P4

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 16 kPa ( 1.6 m) After Pressure



30°  
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0°

350°  
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USRD NO: 0695-65  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
Before Pressure  
XY Plane  
10 kHz

30°  
330°

20°  
340°

10°  
350°

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350°  
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340°  
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330°  
30°

USRD NO: 0695-66  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
Before Pressure  
XY Plane  
20 kHz

320°

40°

310°

50°

300°

60°

290°

70°

280°

80°

270°

90°

260°

100°

250°

110°

240°

120°

230°

130°

220°

140°

210°

150°

200°

160°

190°

170°



30°  
330°

20°  
340°

10°  
350°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-67  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
Before Pressure  
XY Plane  
50 kHz



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-68  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
Before Pressure  
XY Plane  
100 kHz

32°  
40°

31°  
50°

30°  
60°

29°  
70°

28°  
80°

27°  
90°

26°  
100°

25°  
110°

24°  
120°

23°  
130°

22°  
140°

170°

160°

150°

140°

130°

120°

110°

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-69  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
XY Plane  
10 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-70  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

210°  
150°

200°  
160°

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
XY Plane  
20 kHz



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-71  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-72  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

0

-10

-20

-30

-40

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
XY Plane  
100 kHz



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

320°  
20°

330°  
30°

USRD NO: 0695-73  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

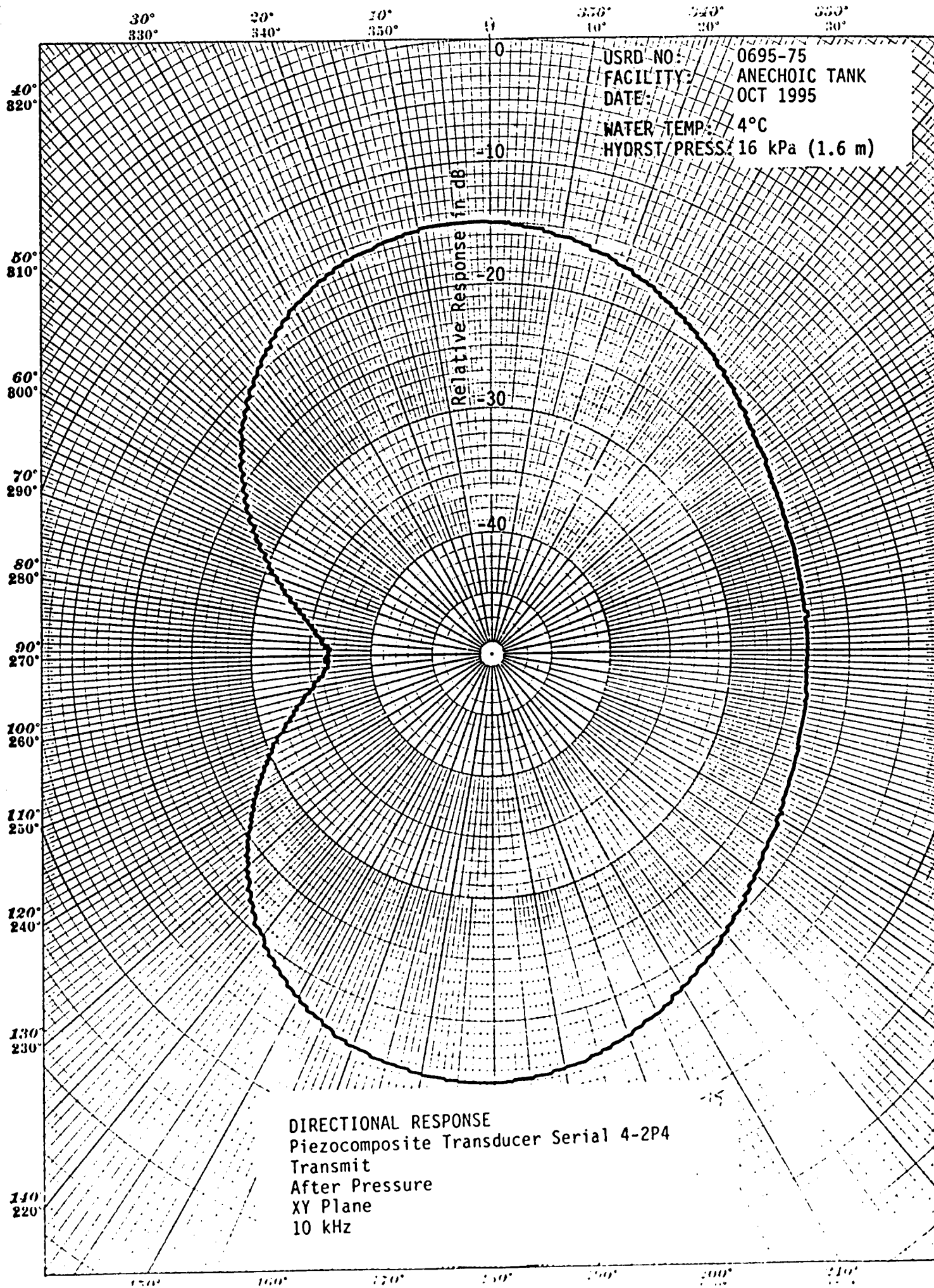
340°  
20°

330°  
30°

USRD NO: 0695-74  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
XY Plane  
100 kHz



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-76  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

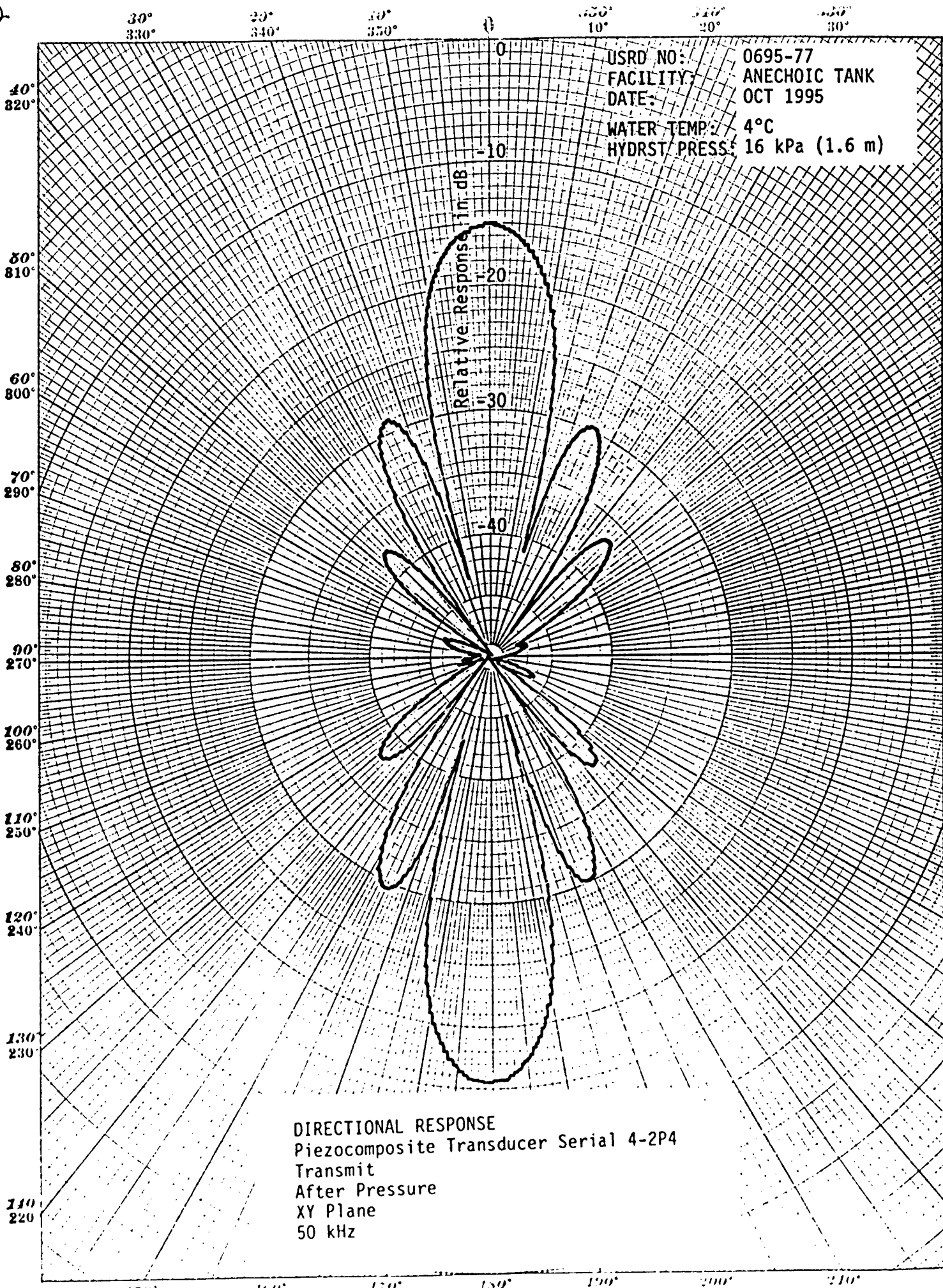
-20

-30

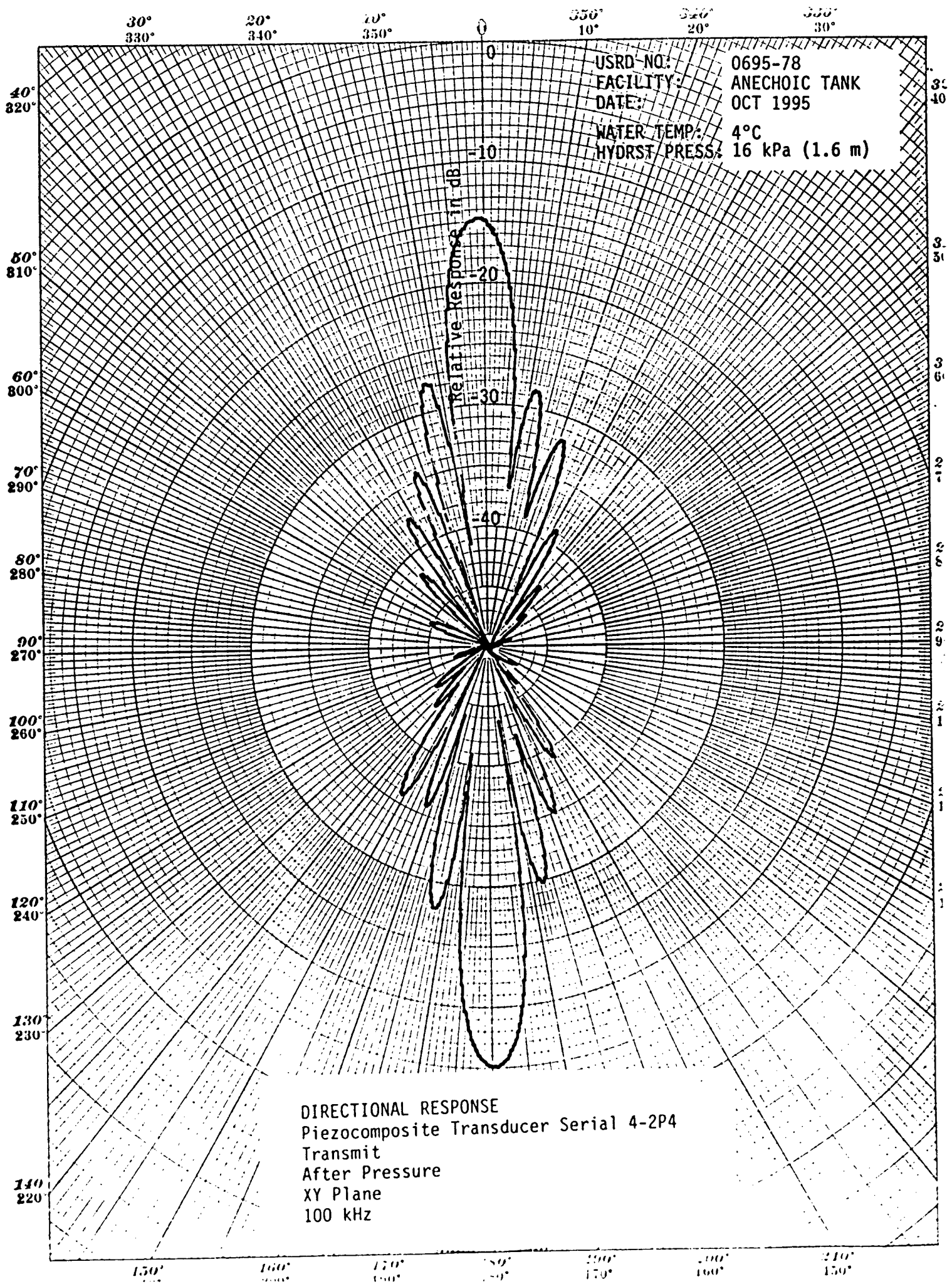
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
After Pressure  
XY Plane  
20 kHz









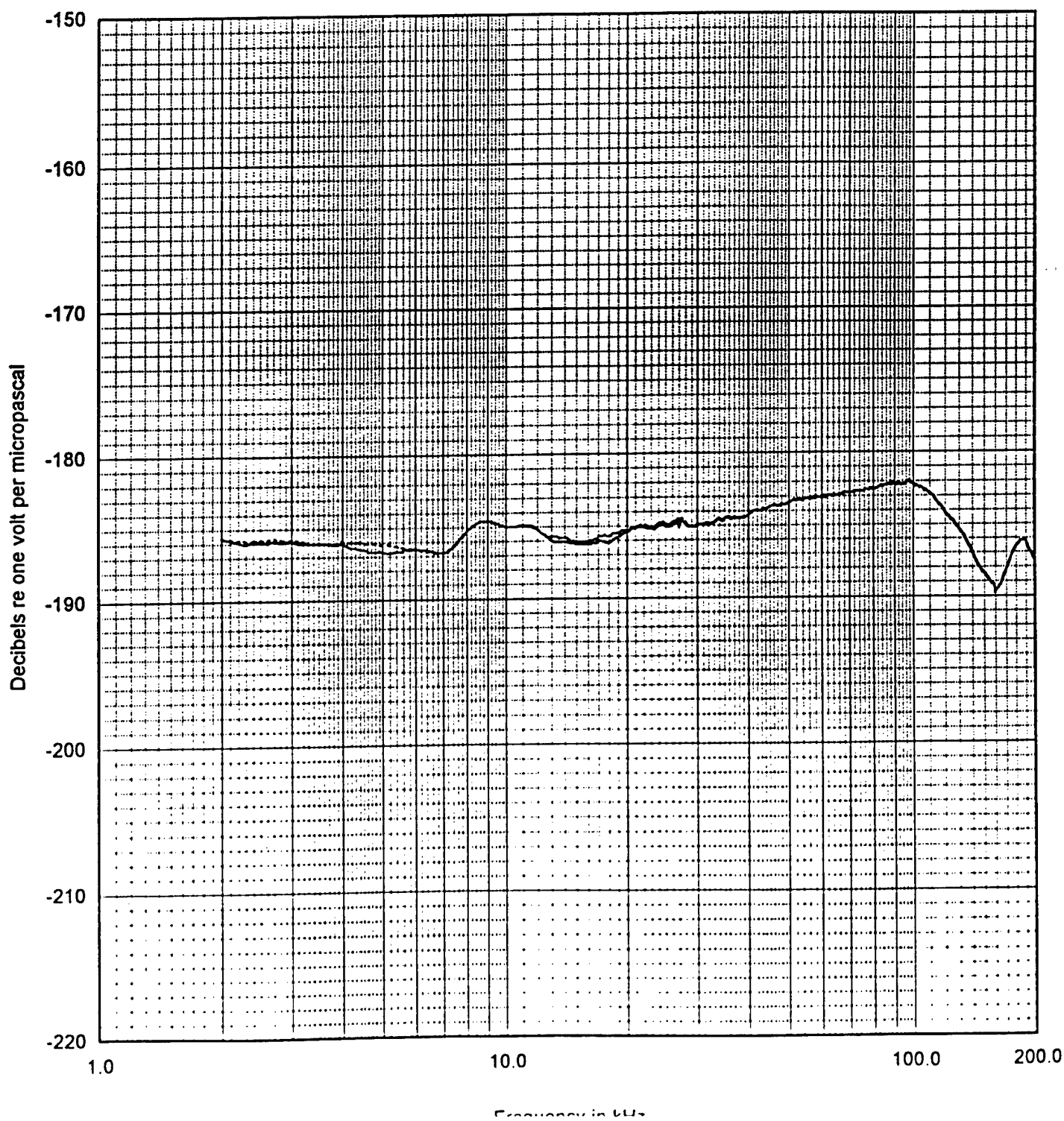
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-2P4

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa (1.6 m) Before Pressure  
----- 16 kPa (1.6 m) After Pressure



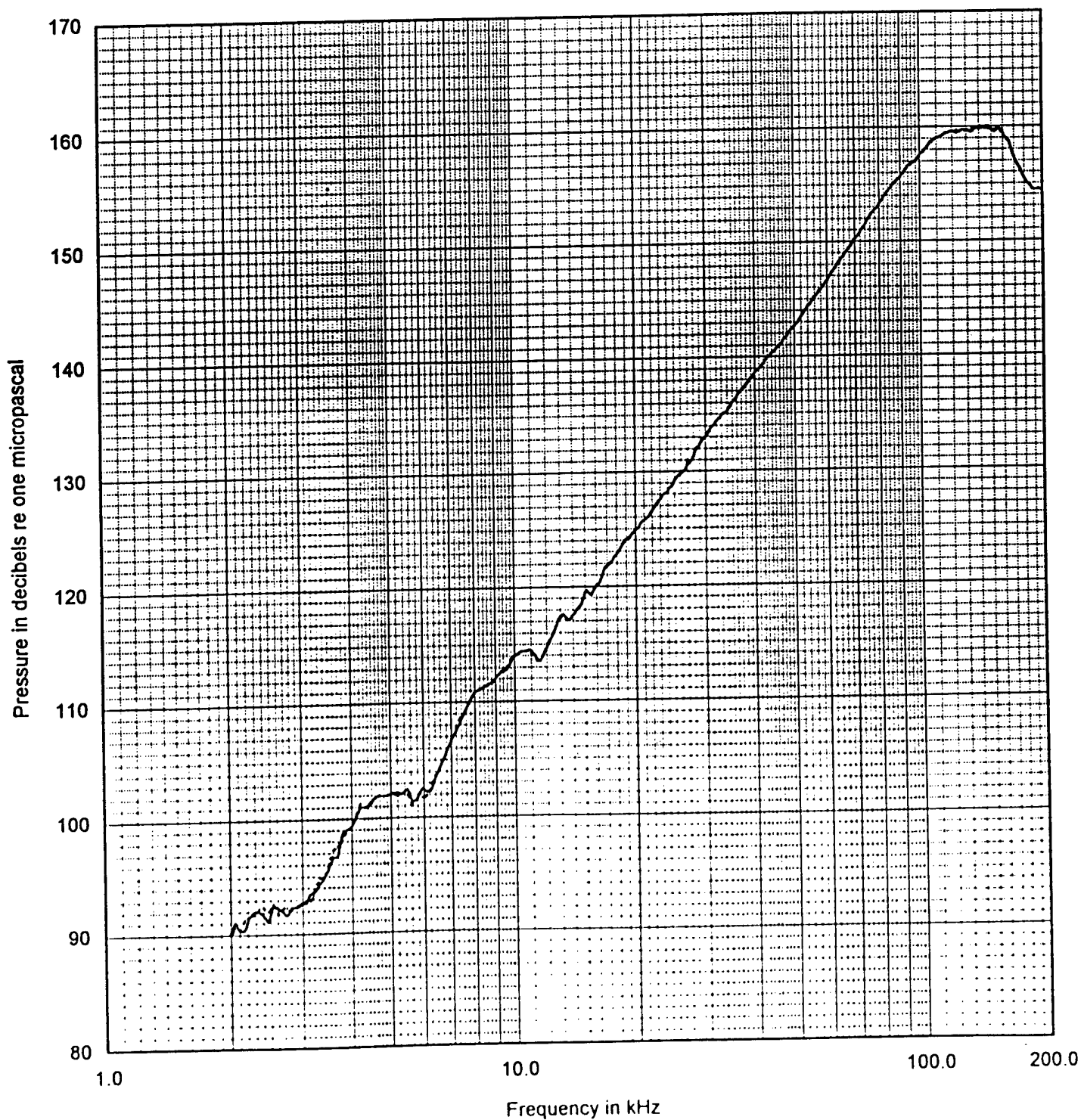
## TRANSMITTING VOLTAGE RESPONSE

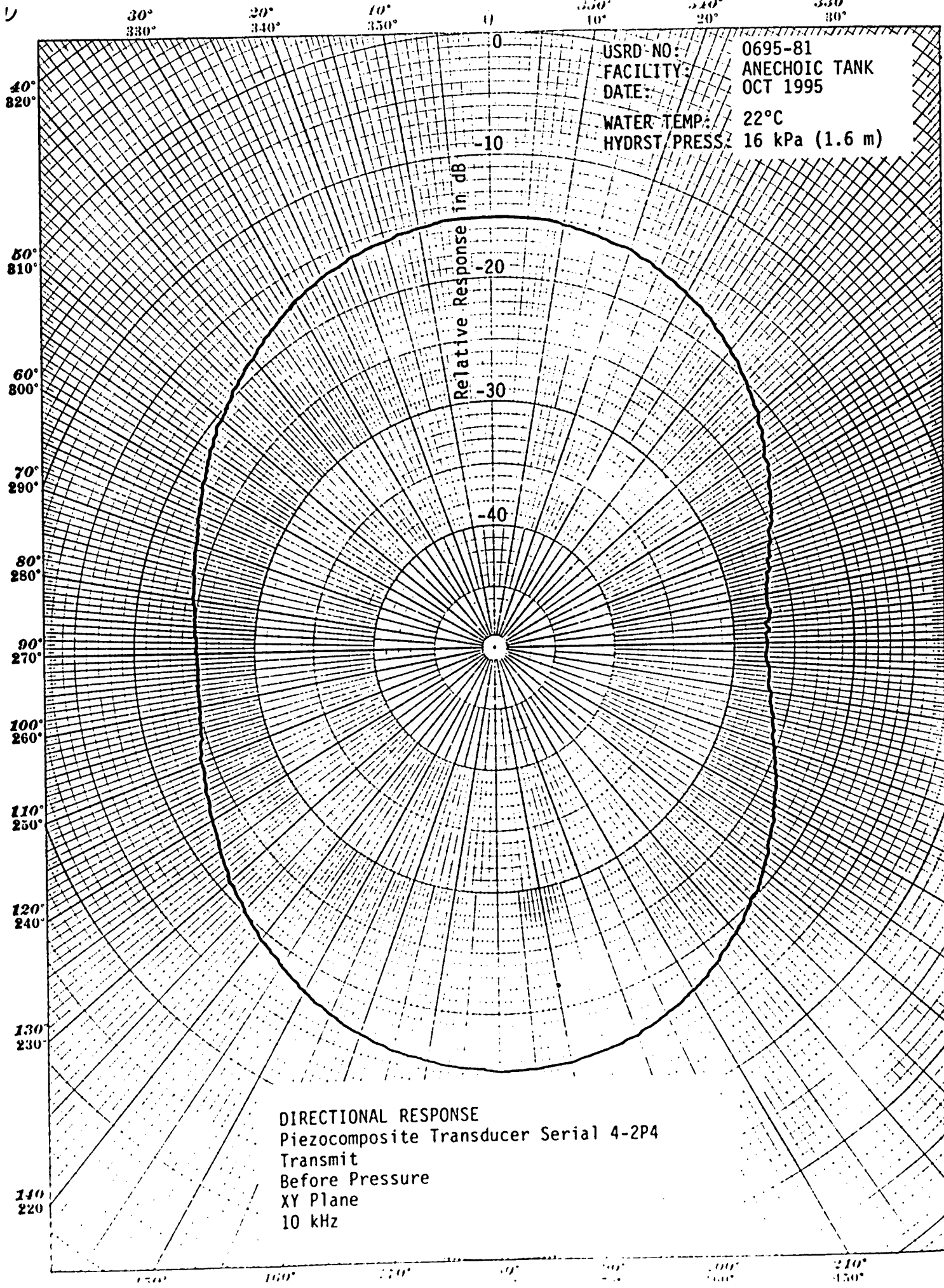
Piezocomposite Transducer Serial 4-2P4

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

— 16 kPa (1.6 m) Before Pressure  
- - - 16 kPa (1.6 m) After Pressure





30°  
330°

20°  
340°

10°  
350°

0°

300°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-82  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

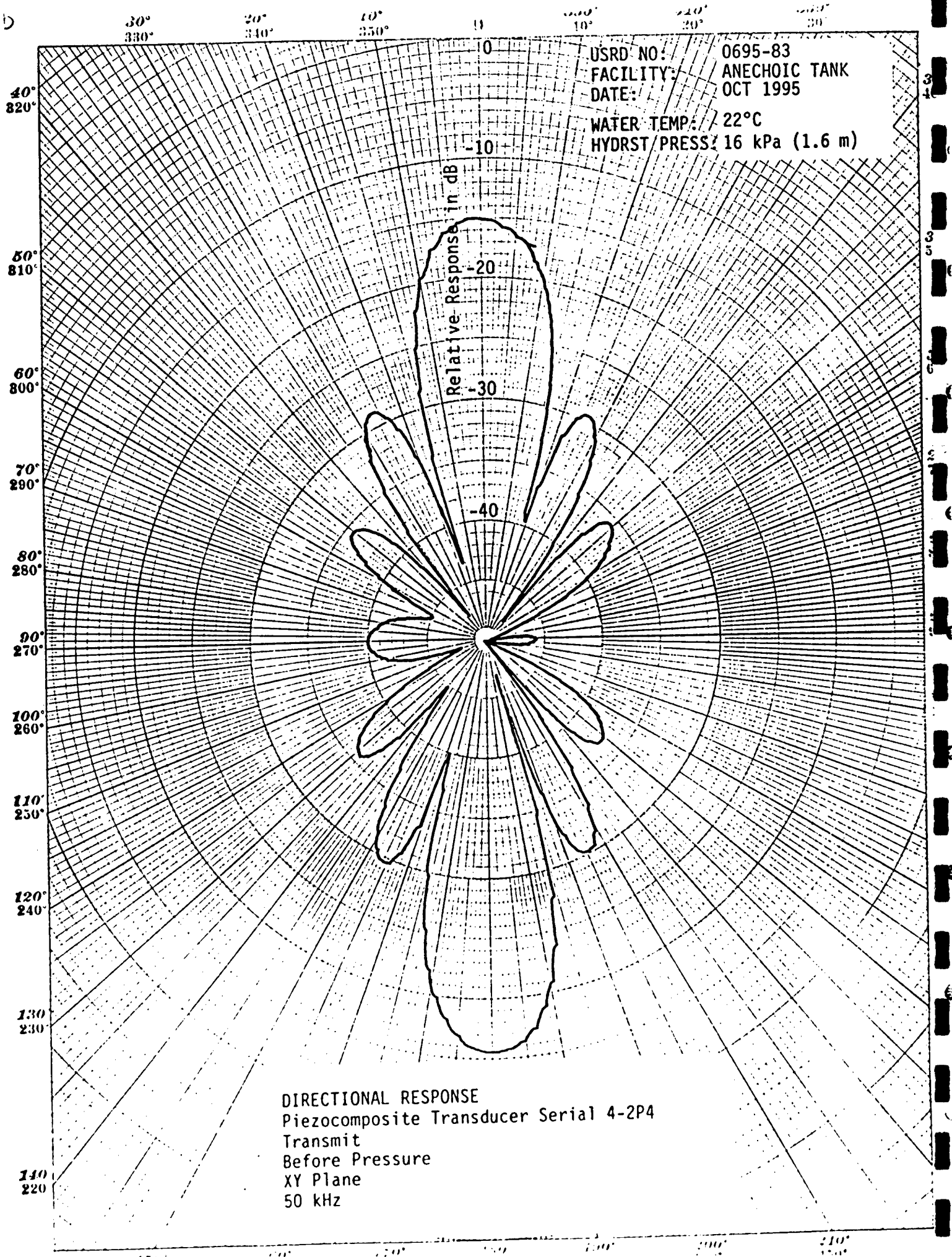
-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
Before Pressure  
XY Plane  
20 kHz





9

30°  
330°20°  
340°10°  
350°0°  
360°10°  
350°20°  
340°30°  
330°40°  
320°50°  
310°60°  
300°70°  
290°80°  
280°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°

USRD NO: 0695-84  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
Before Pressure  
XY Plane  
100 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-85  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

-20

-30

-40

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

210°  
150°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
After Pressure  
XY Plane  
10 kHz

150°

160°

170°

180°

190°

200°

210°

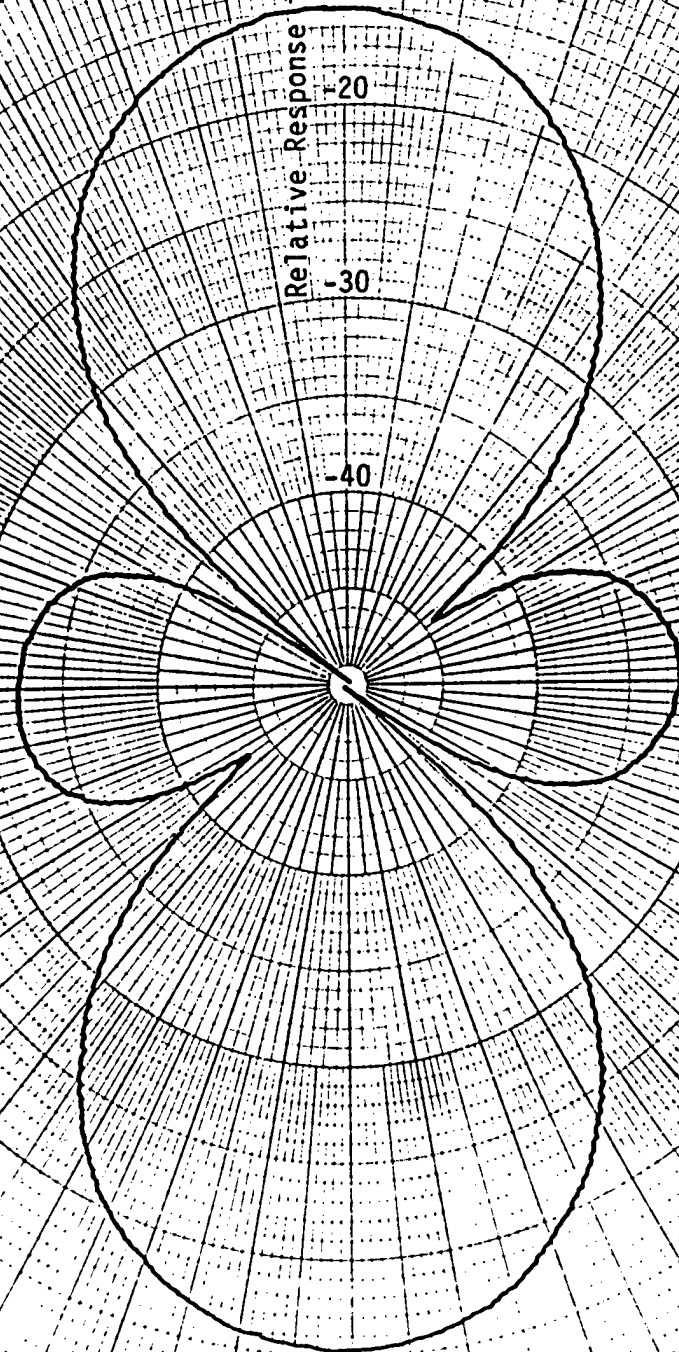
34

30° 20° 10° 0° 10° 20° 30°  
330° 340° 350° 360° 370° 380° 390°

USRD NO: 0695-86  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0  
-10  
-20  
-30  
-40



DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
After Pressure  
XY Plane  
20 kHz

150° 160° 170° 180° 190° 200° 210°  
220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320° 330° 340° 350° 360°



30°  
330°

20°  
340°

10°  
350°

0°

330°  
10°

340°  
20°

350°  
30°

USRD NO: 0695-87  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
After Pressure  
XY Plane  
50 kHz



60

30° 330°    20° 340°    10° 350°    0°    350° 10°    340° 20°    330° 30°

USRD NO: 0695-88  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 16 kPa (1.6 m)

40°  
820°

50°  
810°

60°  
800°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-2P4  
Transmit  
After Pressure  
XY Plane  
100 kHz

150° 160° 170° 180° 190° 200° 210°

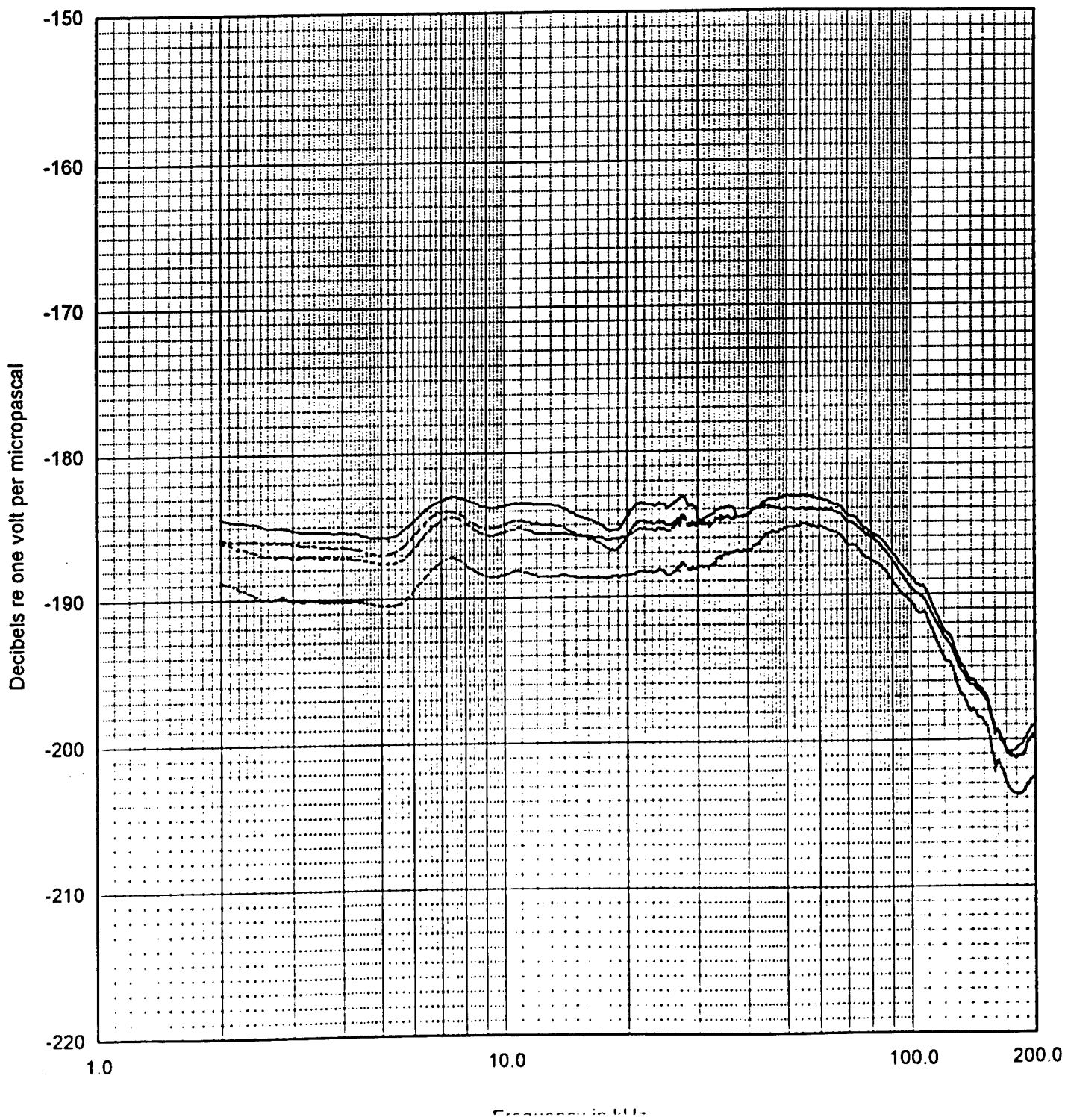
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 7.5

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



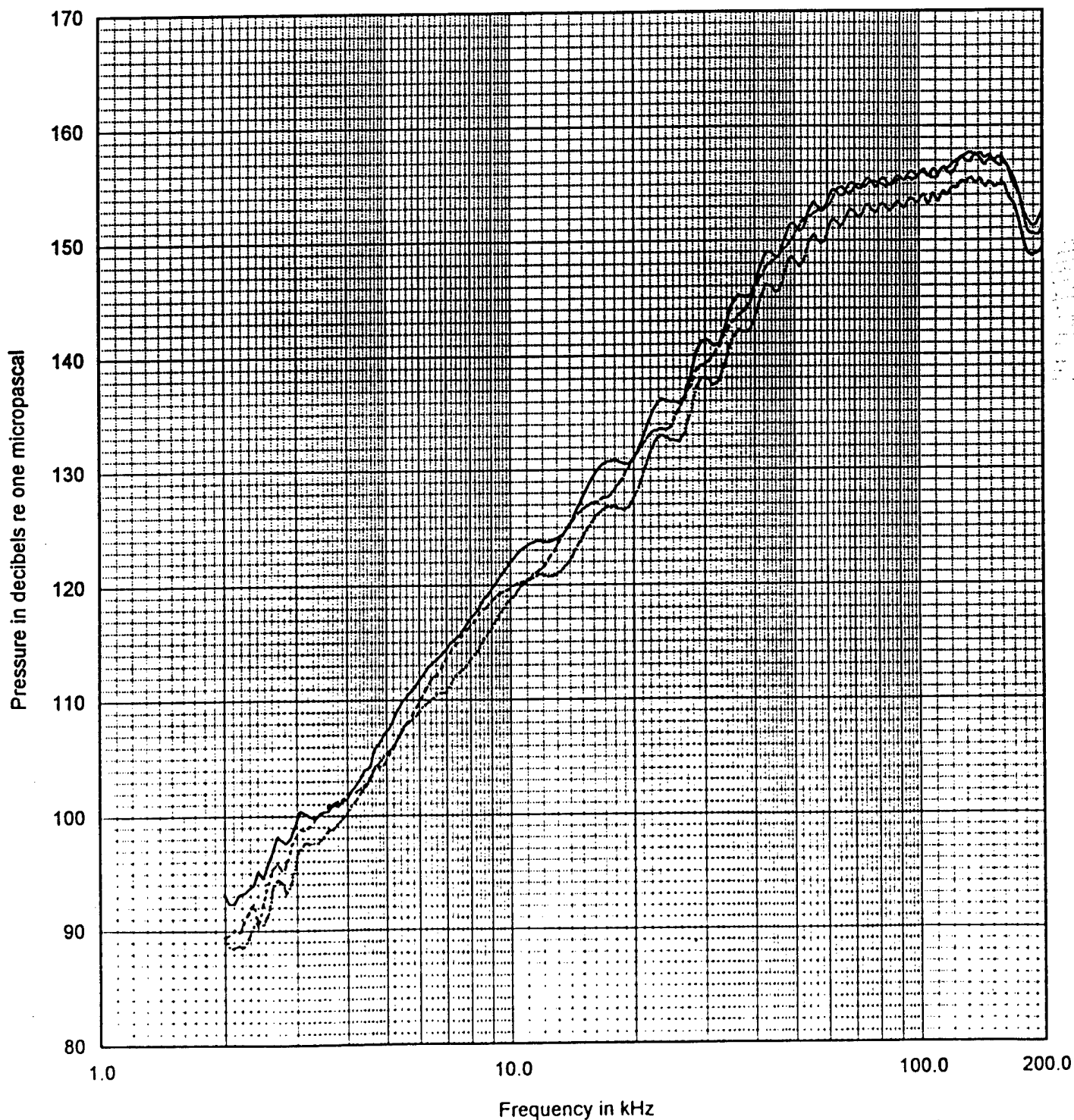
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 7.5

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
..... 16 kPa ( 1.6 m) After Pressure



30°  
330°

20°  
340°

10°  
350°

0°

300°  
10°

240°  
20°

210°  
30°

USRD NO: 0695-91  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

-10

-20

-30

-40

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
Before Pressure  
XY Plane  
10 kHz

150°

160°

170°

180°

190°

200°

210°

150°



30° 20° 10° 0 350° 340° 330° 320° 310° 300°

USRD NO: 0695-92  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
Before Pressure  
XY Plane  
20 kHz

150° 160° 170° 180° 190° 200° 210°  
220° 230° 240° 250° 260° 270° 280° 290° 300° 310° 320° 330° 340° 350°



30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-93  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB  
-10  
-20  
-30  
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
Before Pressure  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

40°  
820°

50°  
810°

60°  
800°

70°  
790°

80°  
780°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

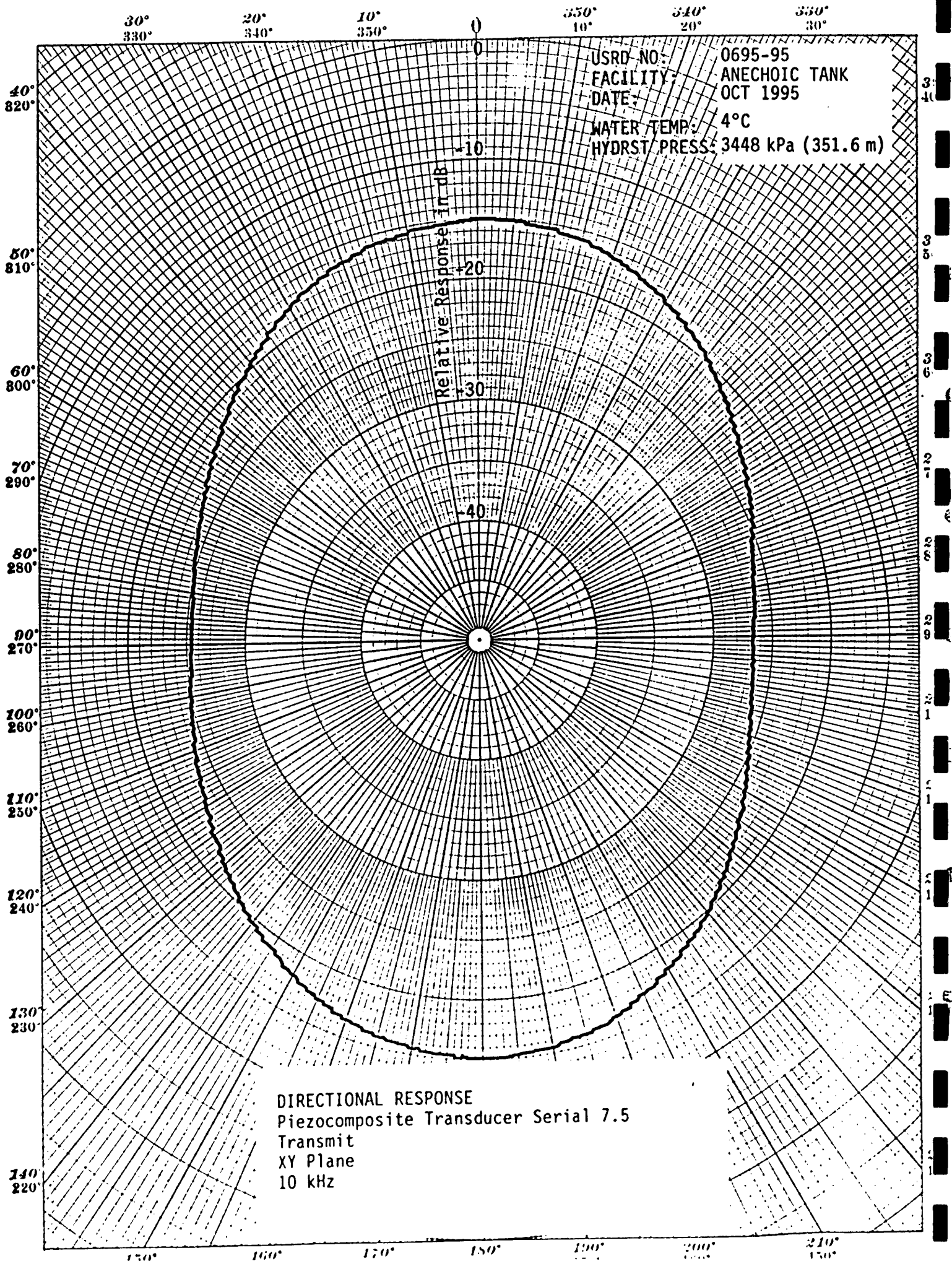
230°  
130°

220°  
140°

USRD NO: 0695-94  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

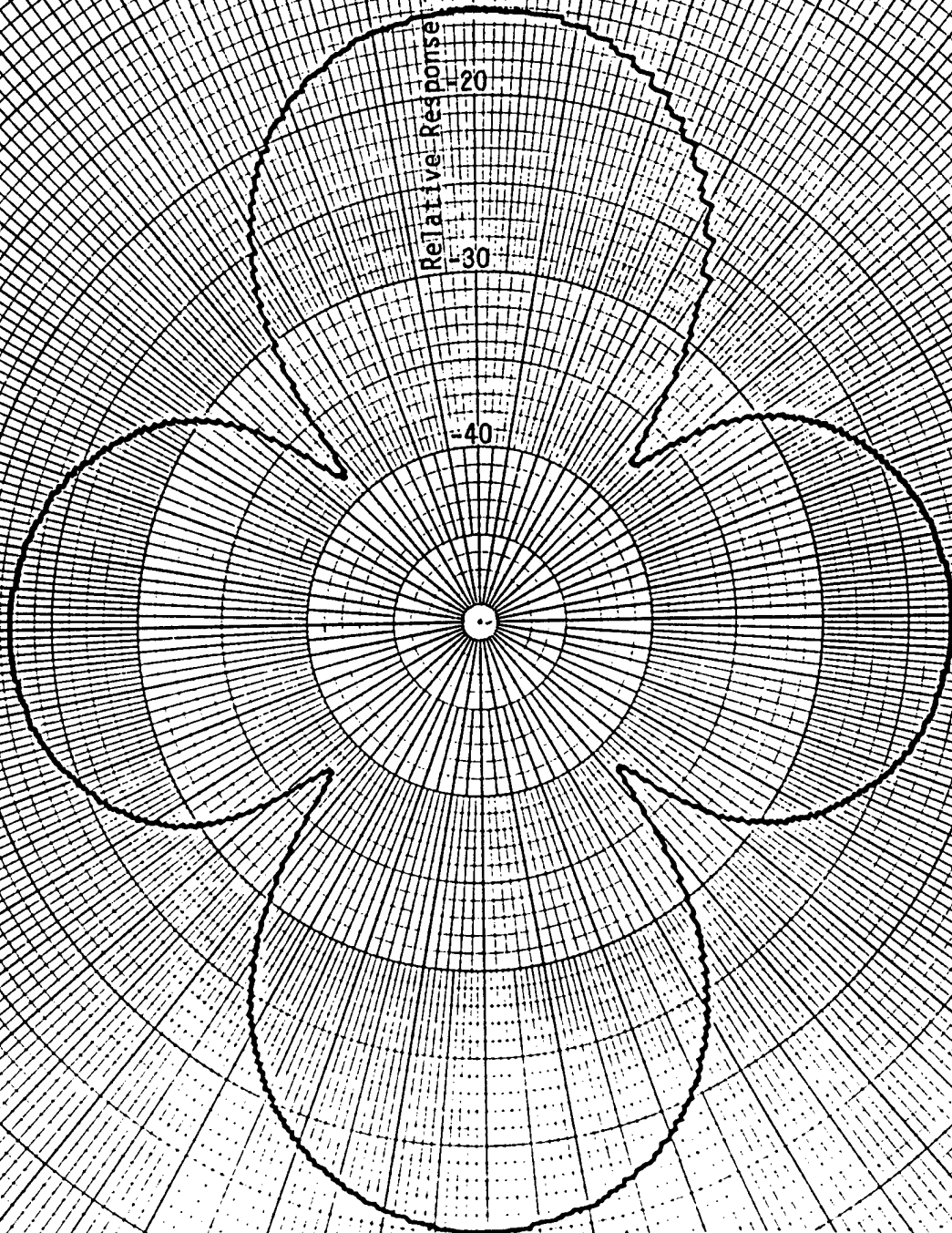
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
Before Pressure  
XY Plane  
100 kHz



30° 20° 10° 0° 350° 340° 330°

USRD NO: 0695-96  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

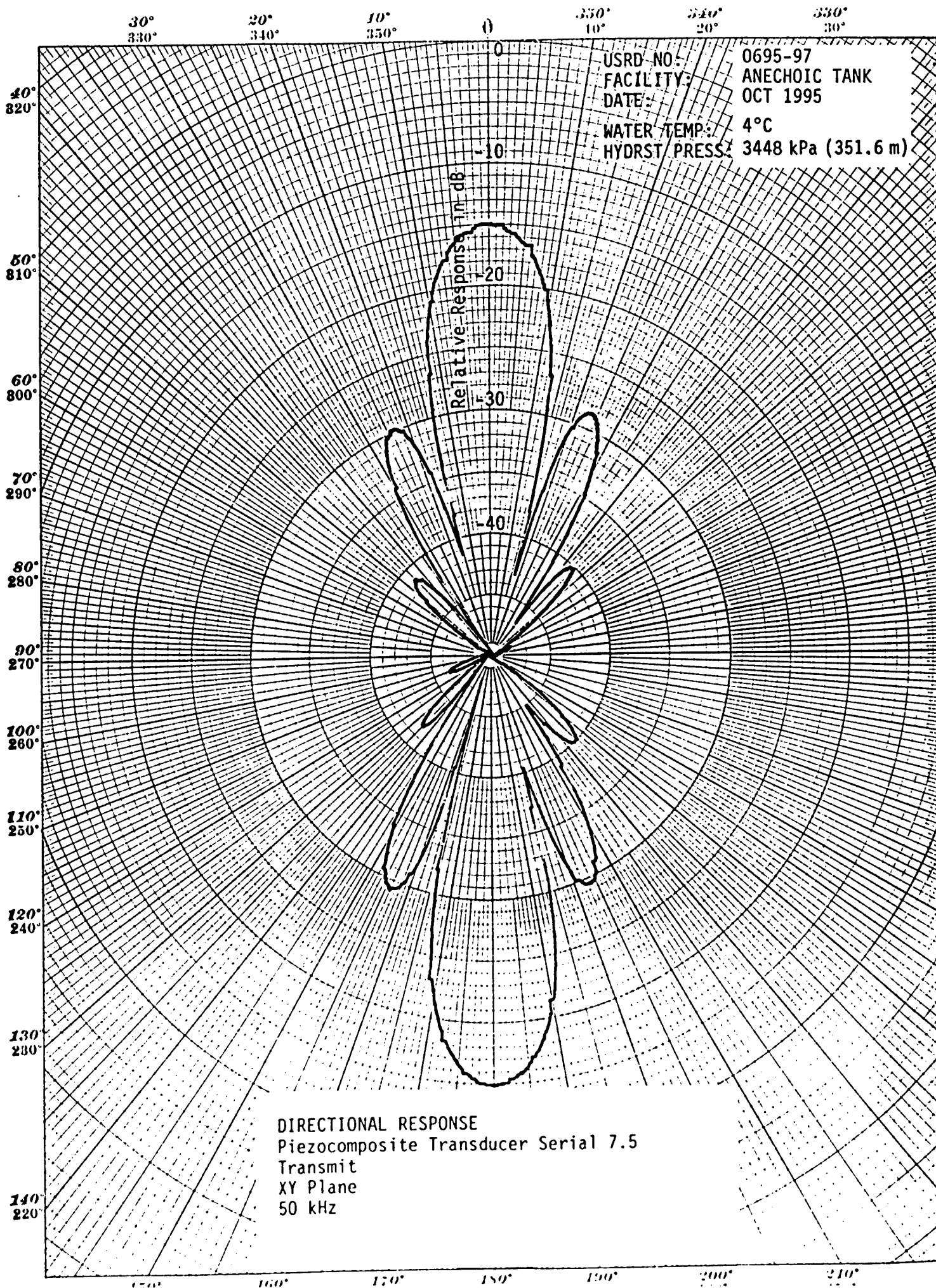
Relative Response in dB



DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
XY Plane  
20 kHz

150° 160° 170° 180° 190° 200° 210°







30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

40°  
820°

50°  
810°

60°  
800°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

32°  
40°

31°  
50°

30°  
60°

29°  
70°

28°  
80°

27°  
90°

26°  
10°

25°  
1°

24°  
1°

23°  
1°

22°  
1°

USRD NO: 0695-98  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
XY Plane  
100 kHz

150°

160°

170°

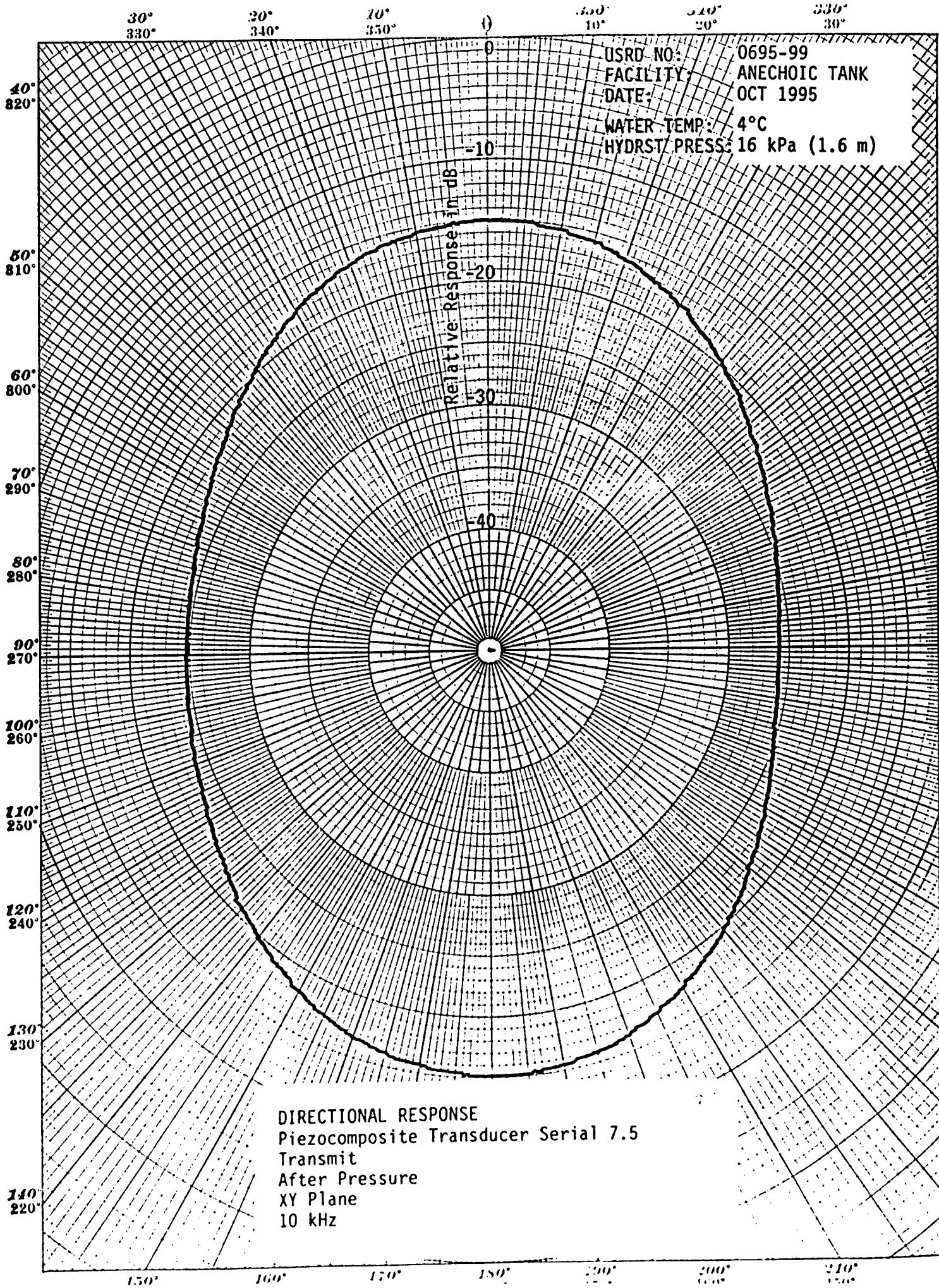
180°

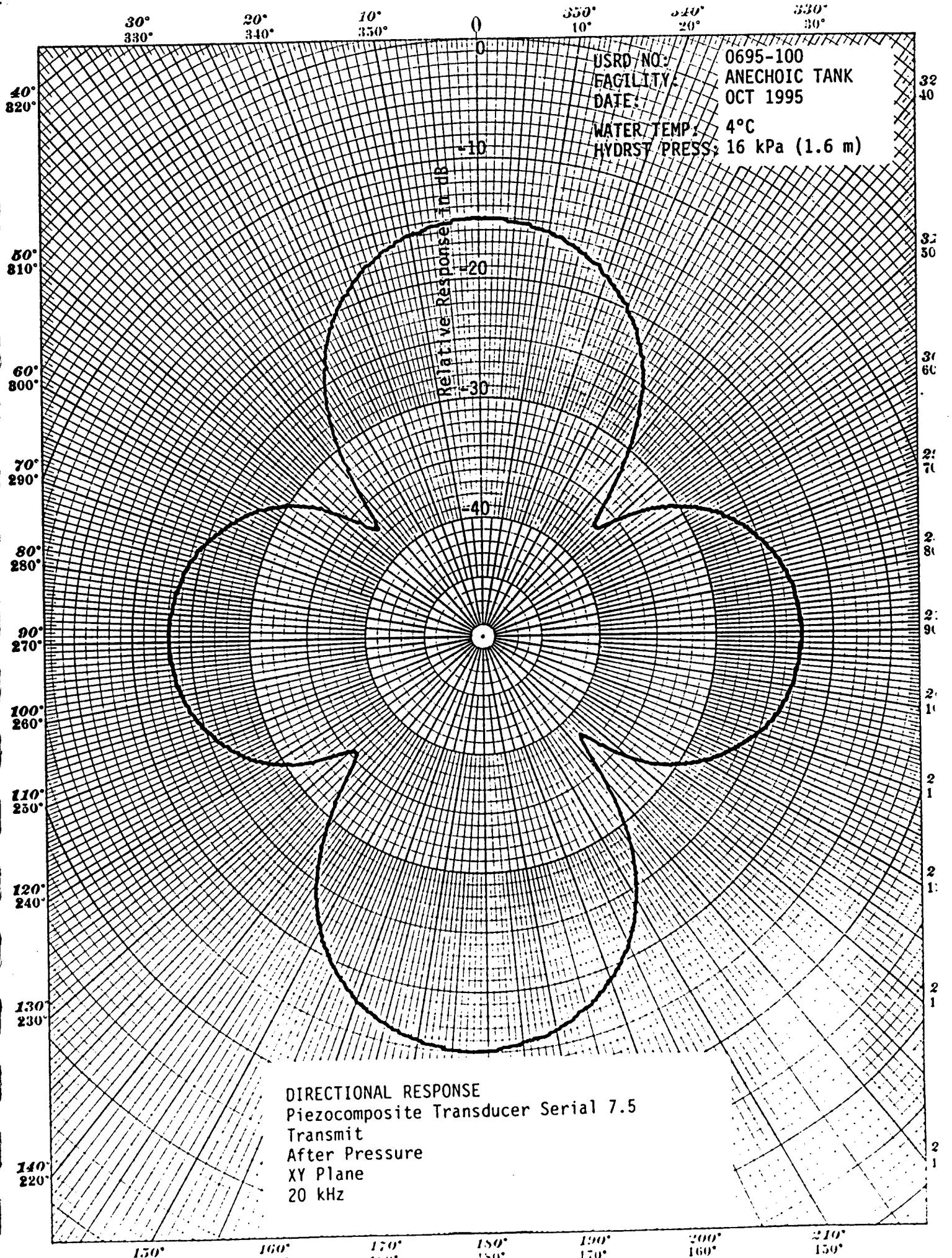
190°

200°

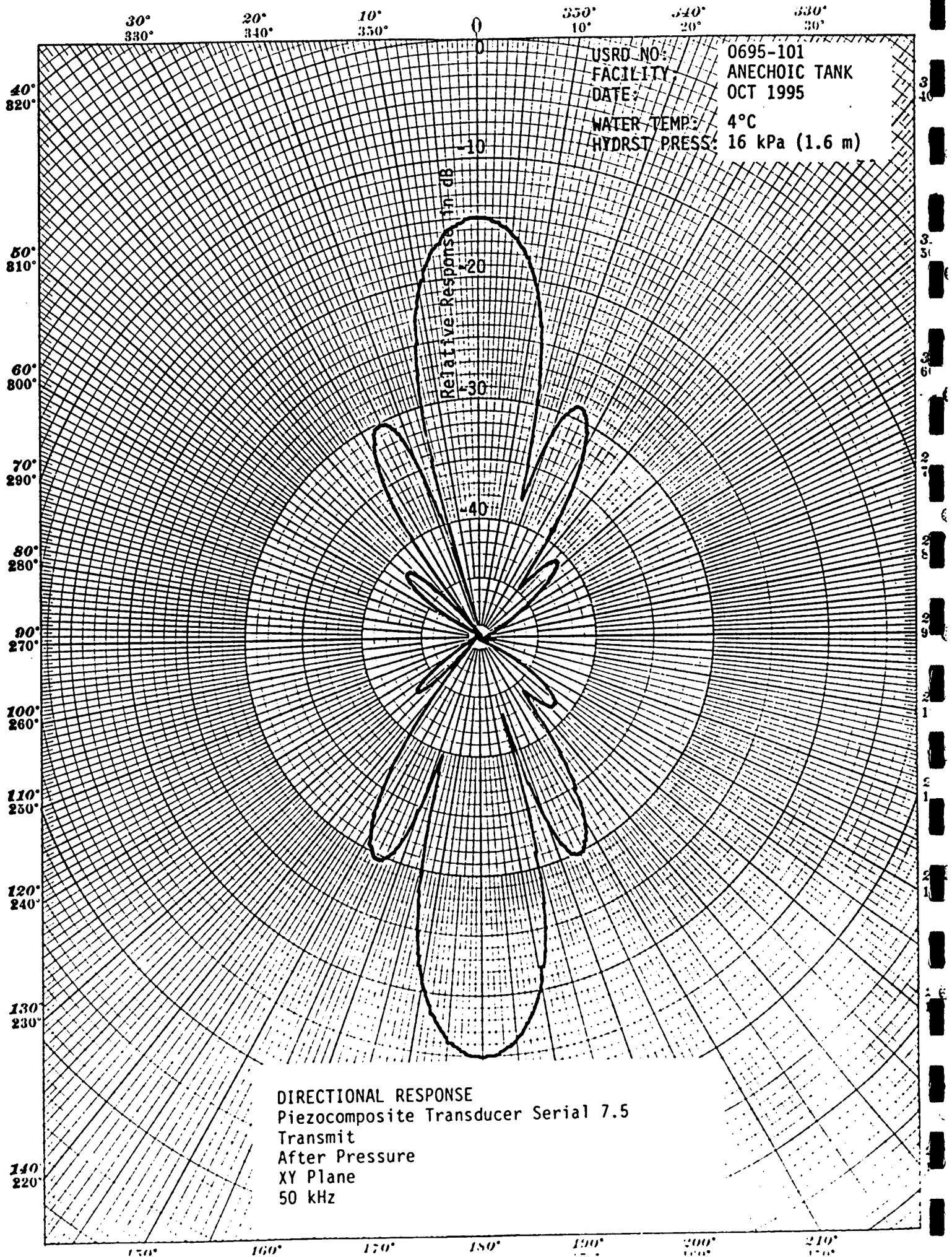
210°

150°





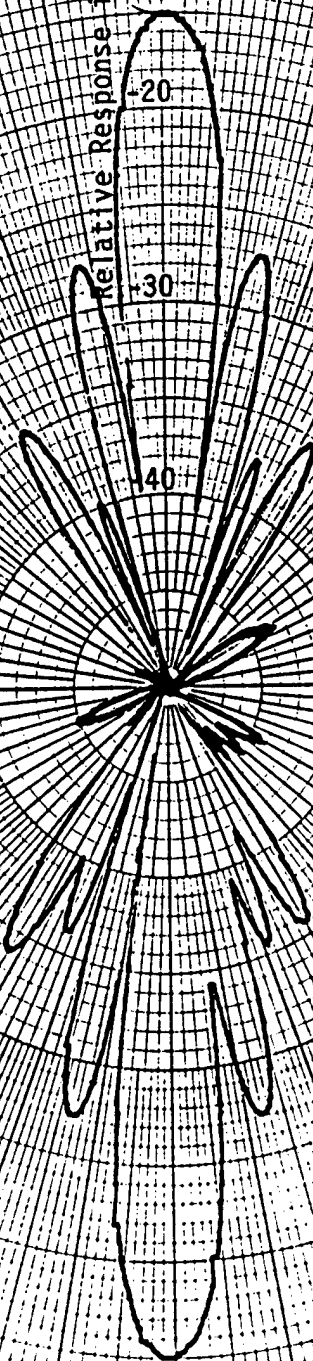




30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 0° 10° 20° 30°

USRD NO: 0695-102  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB



DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
After Pressure  
XY Plane  
100 kHz



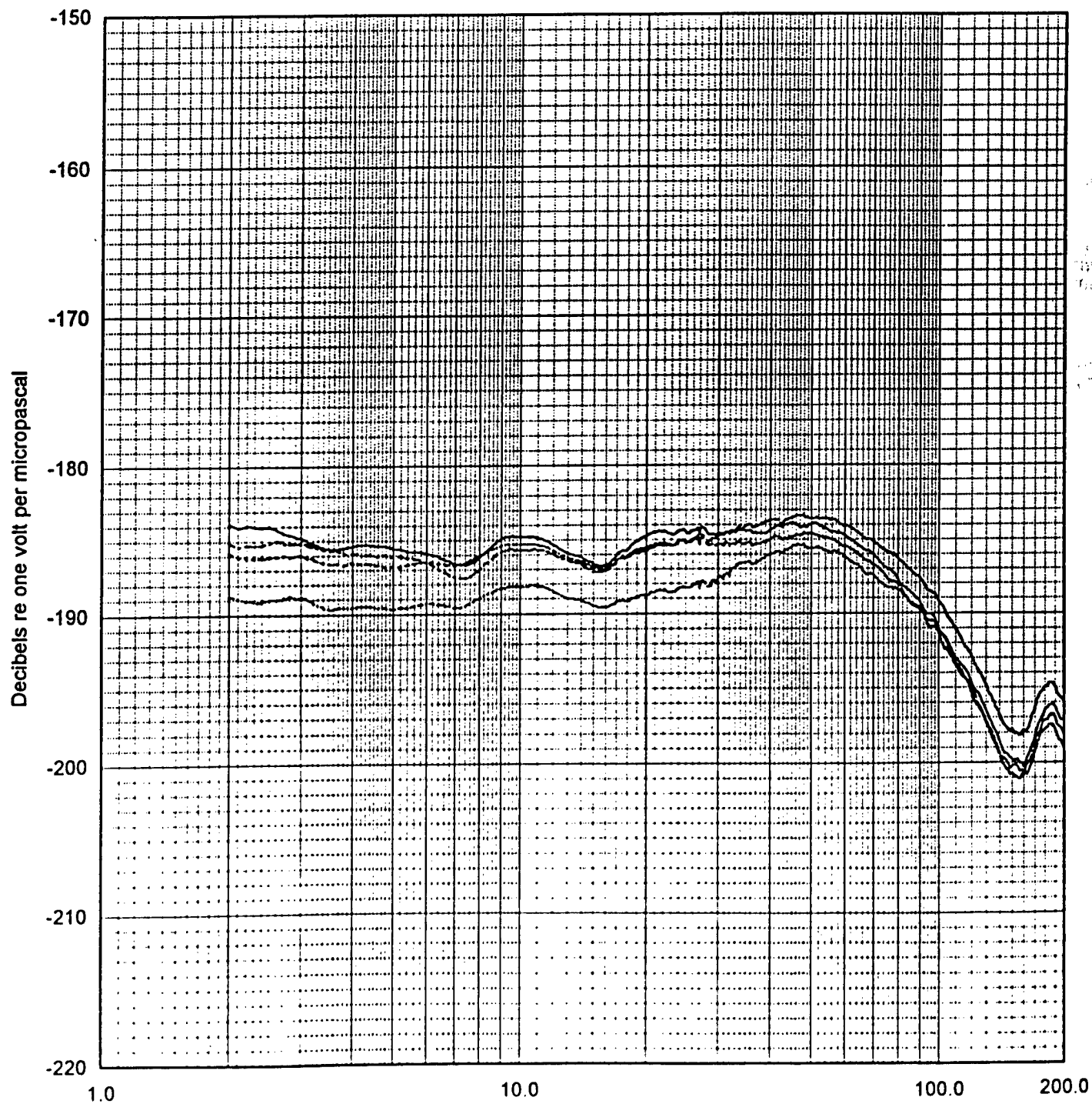
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 7.5

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
- · - · - 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



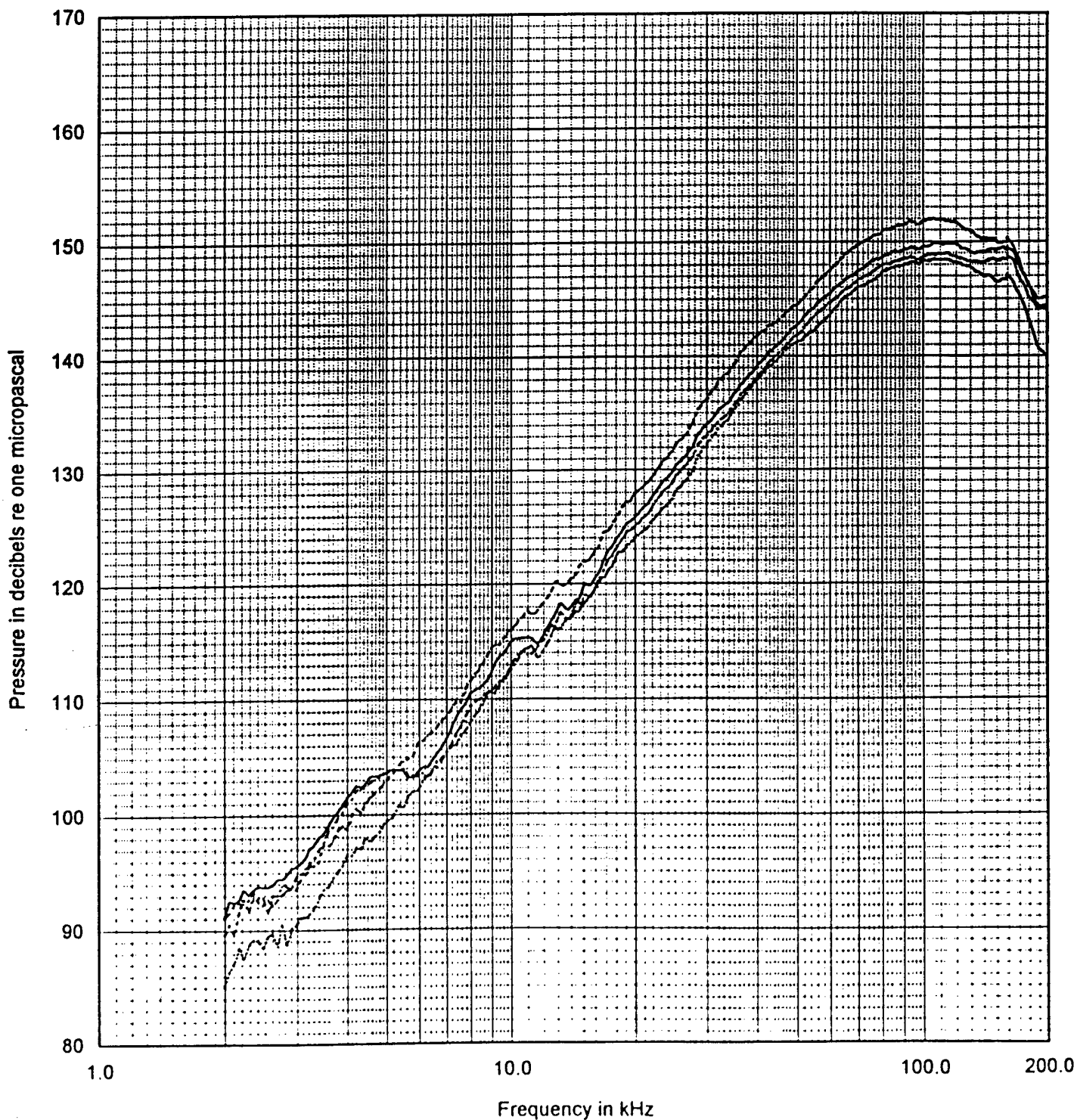
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 7.5

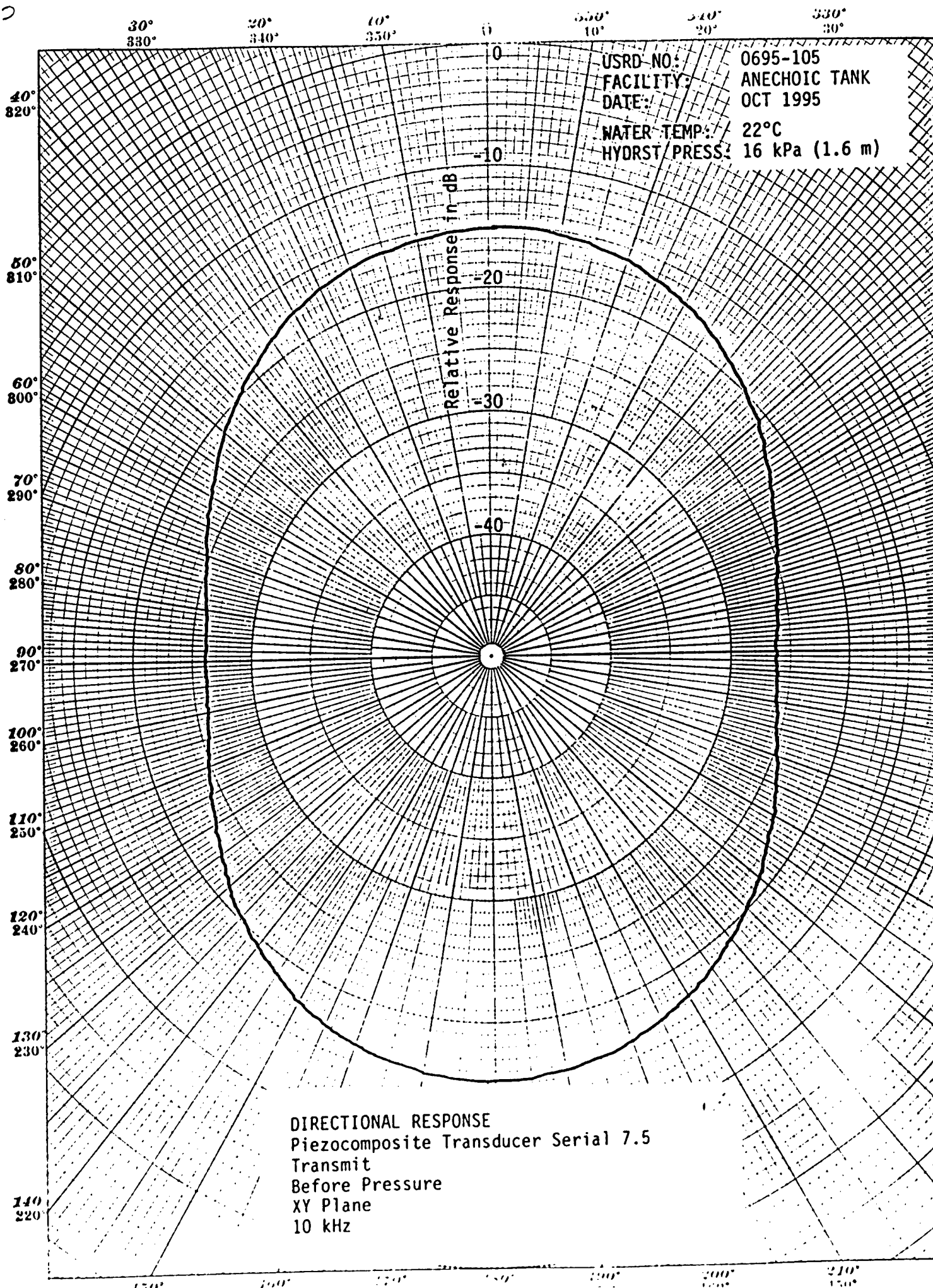
Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
- - - 6895 kPa ( 703.1 m)  
- - - 16 kPa ( 1.6 m) After Pressure



72



30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°

USRD NO: 0695-106  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

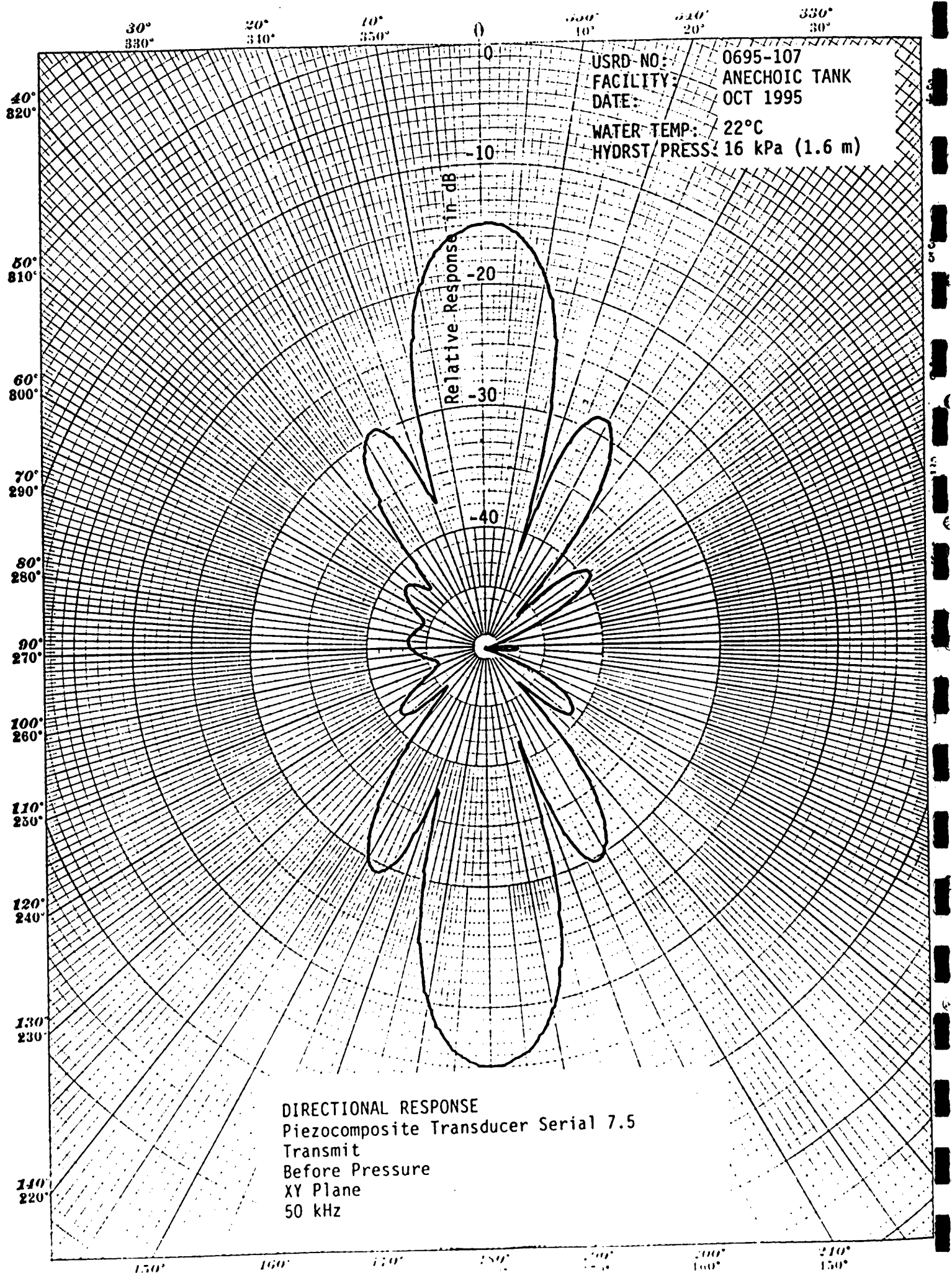
-10

-20

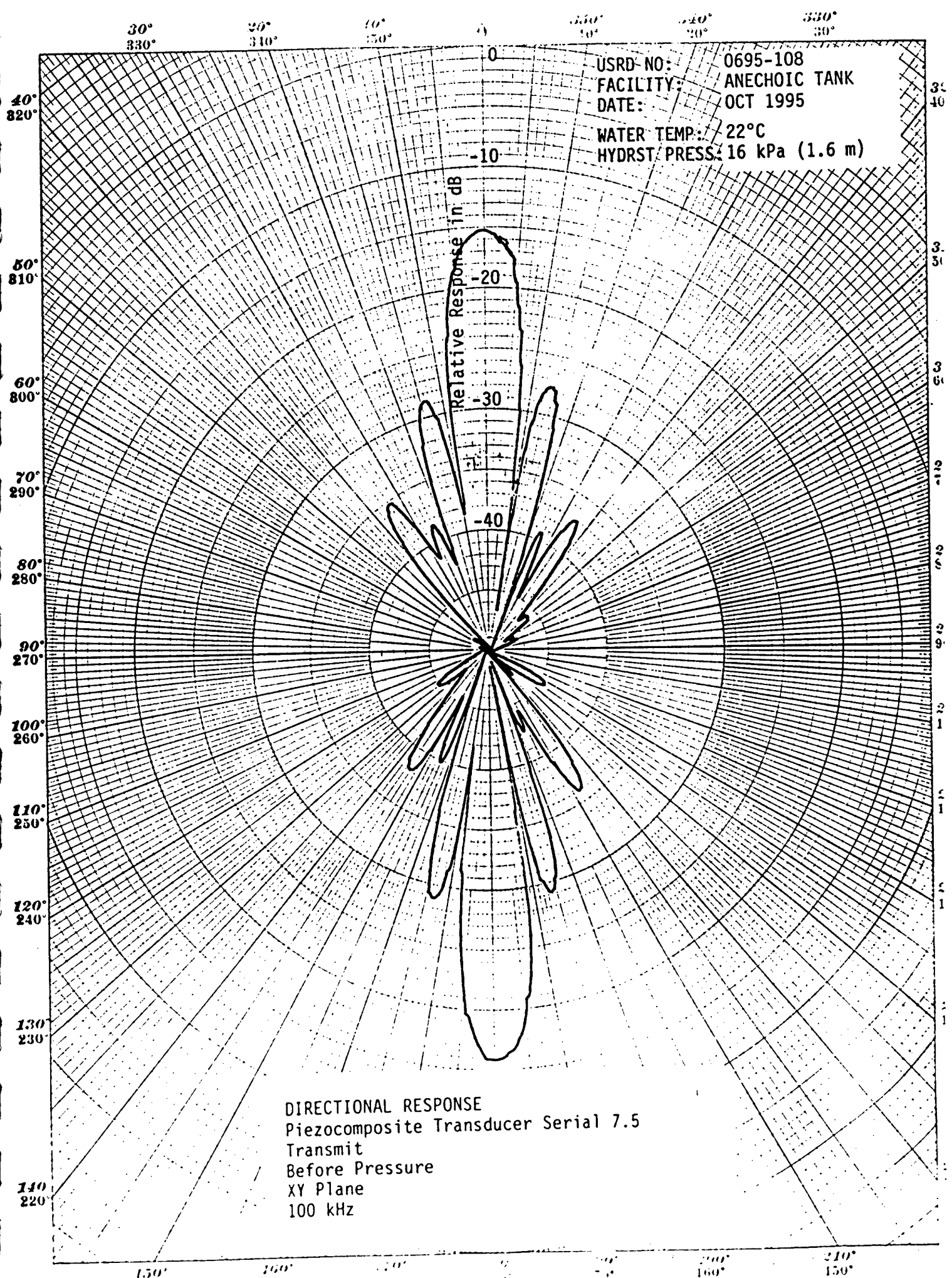
-30

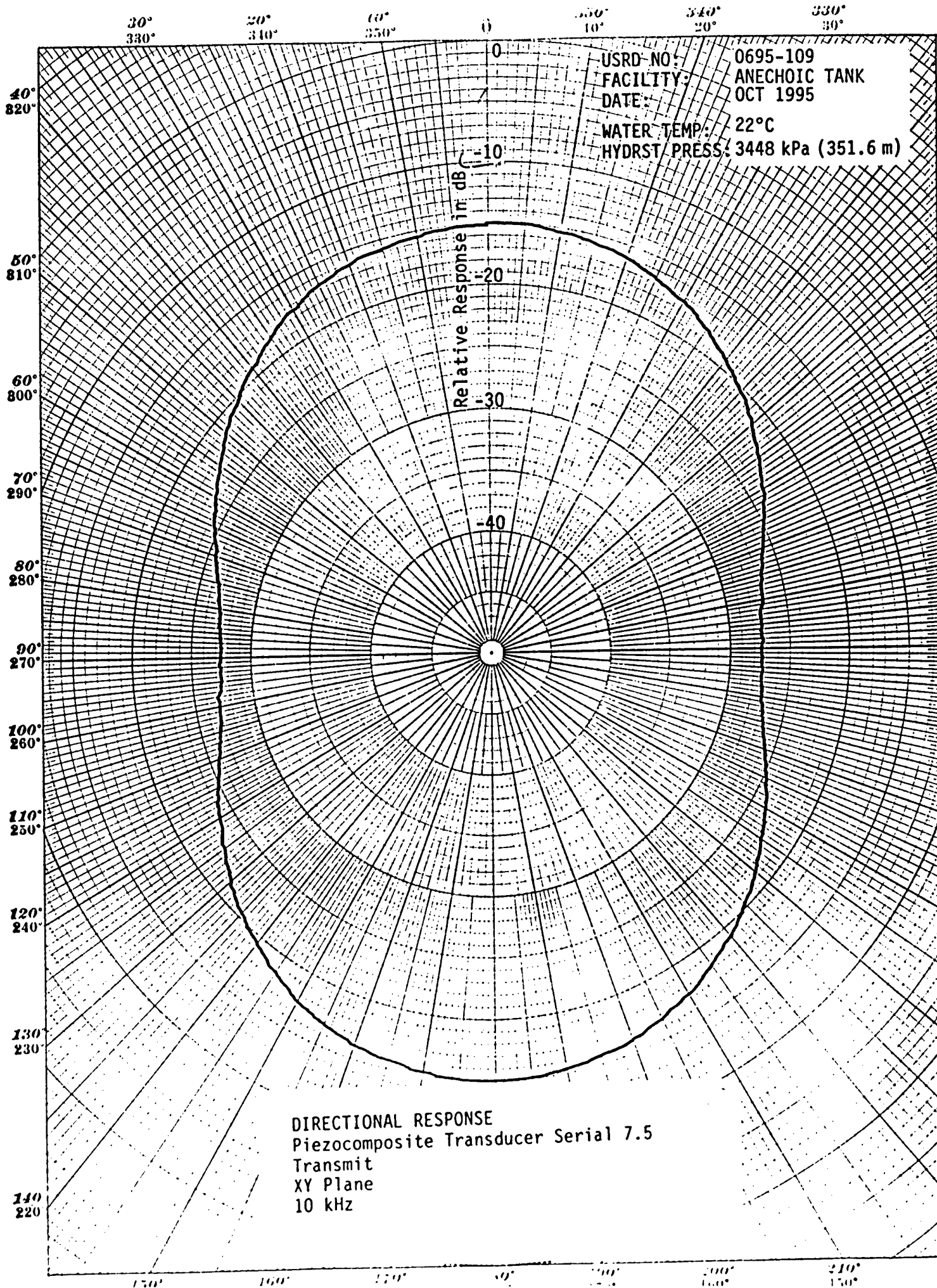
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
Before Pressure  
XY Plane  
20 kHz









30°  
330°

30°  
340°

30°  
350°

30°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-110  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

0

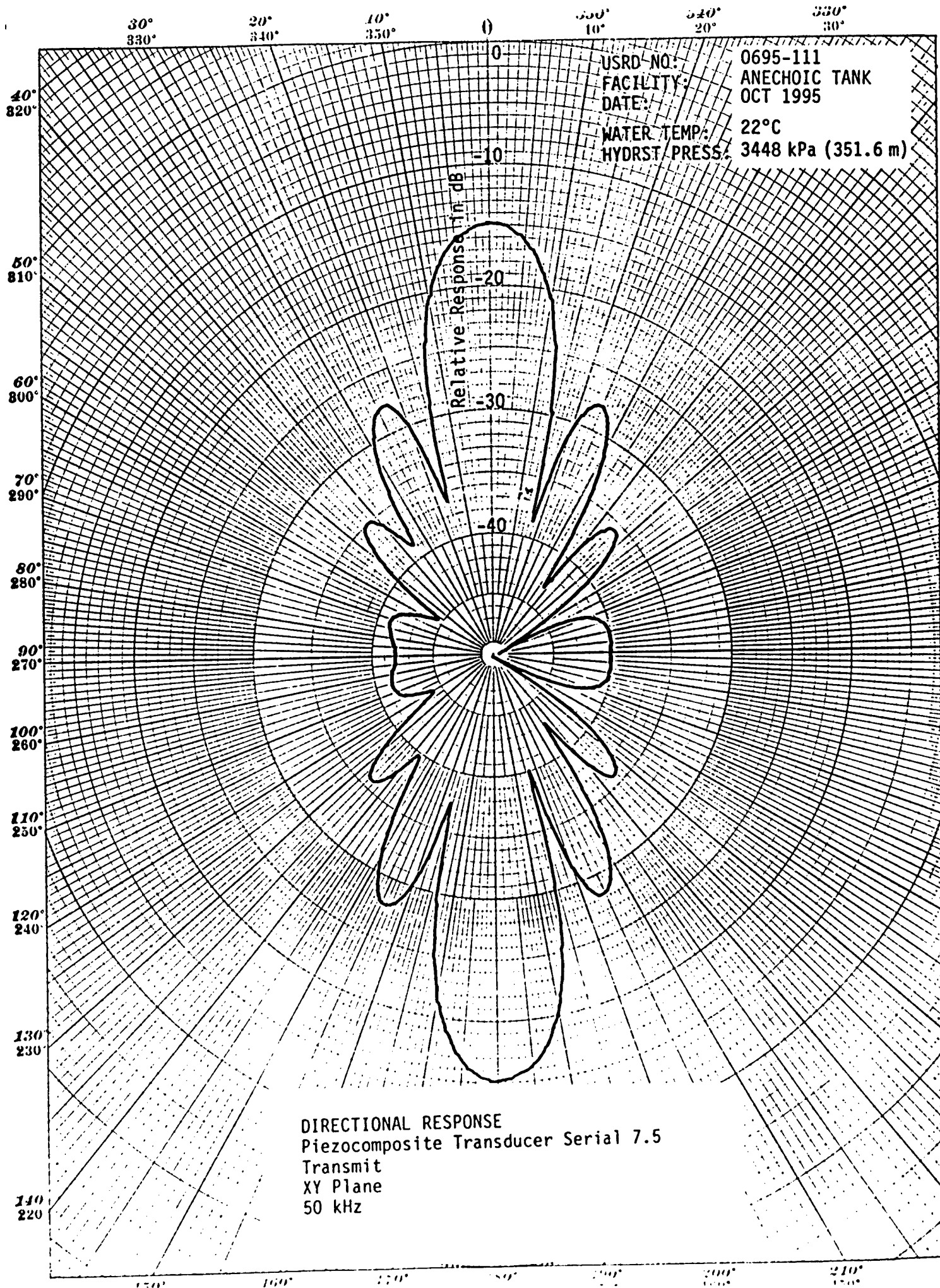
-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
XY Plane  
20 kHz





30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°40°  
320°50°  
310°60°  
300°70°  
290°80°  
280°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°

USRD NO: 0695-112  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

-10

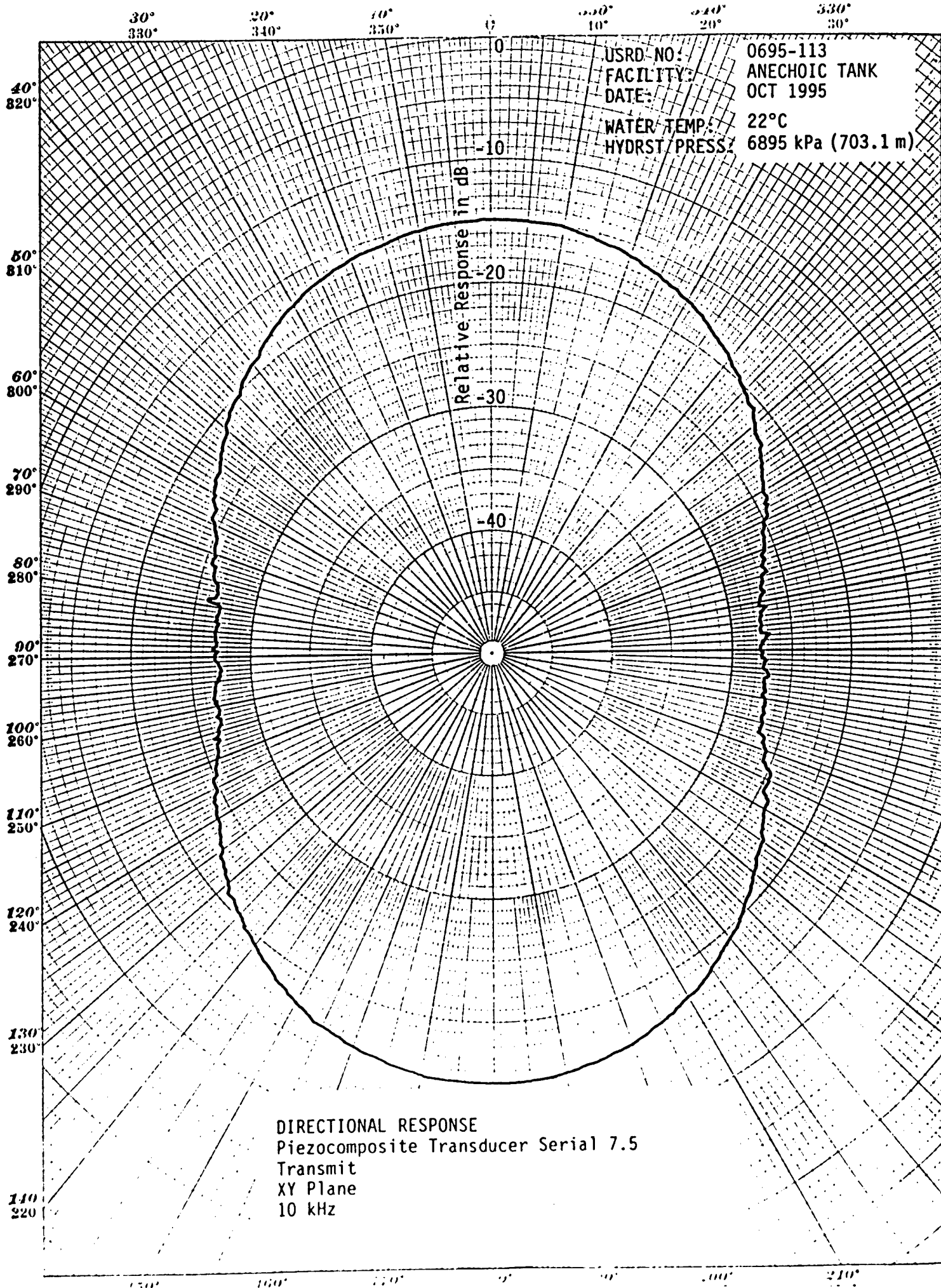
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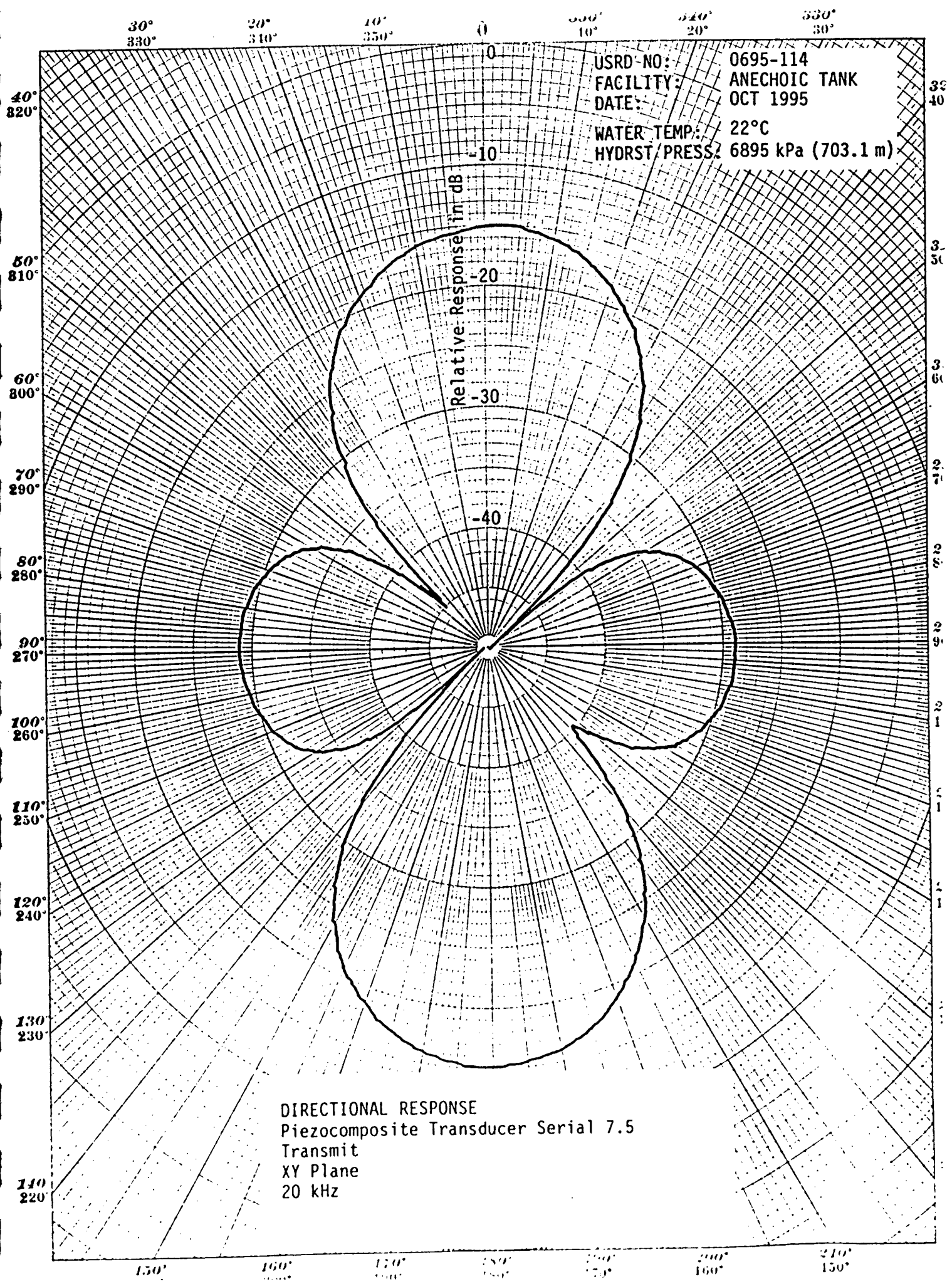
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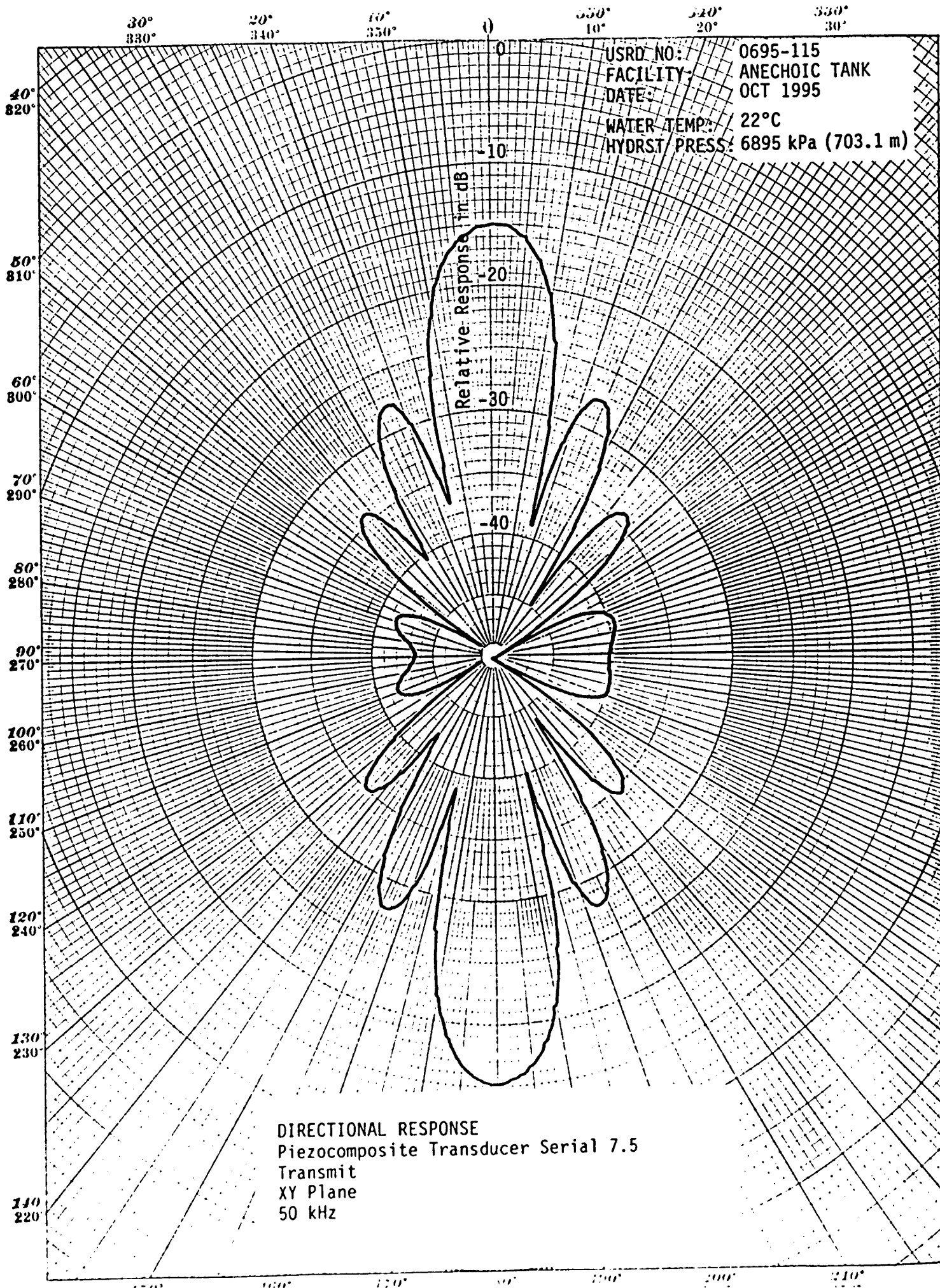
-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
XY Plane  
100 kHz







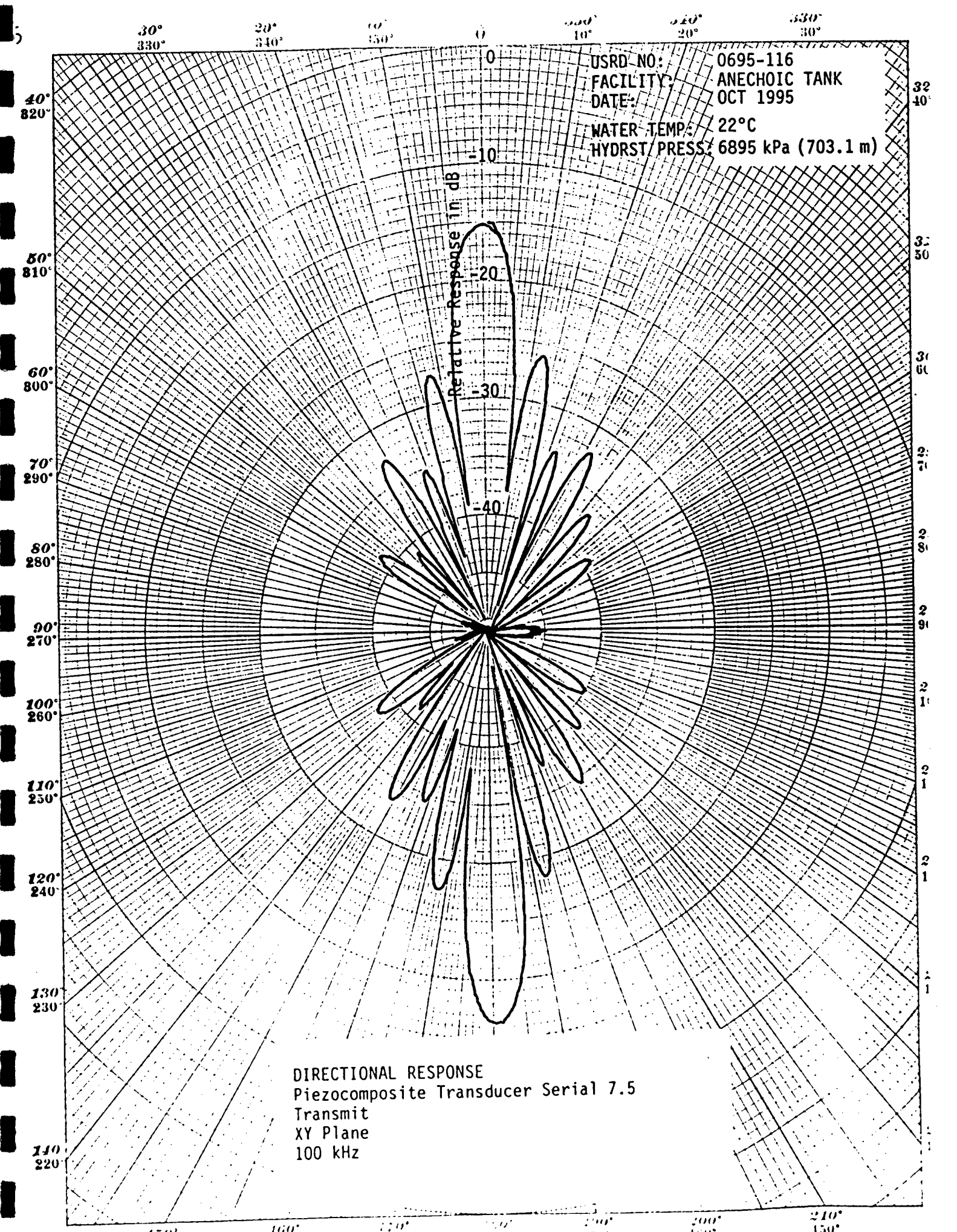


30° 20° 10° 0° 10° 20° 30°  
330° 340° 350° 360° 370° 380° 390°

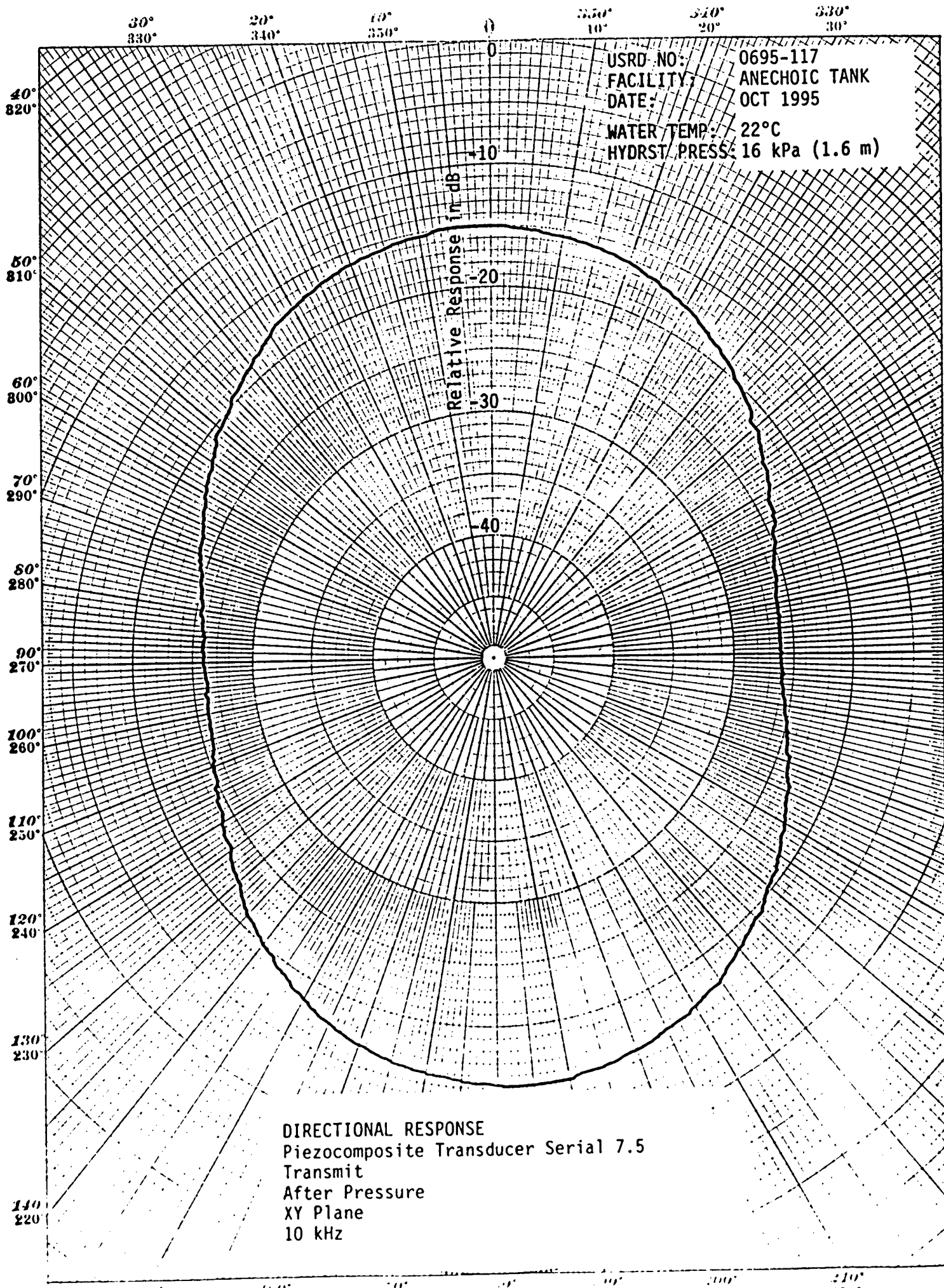
USRD NO: 0695-116  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 6895 kPa (703.1 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
XY Plane  
100 kHz









30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0695-118  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST/PRESS: 16 kPa (1.6 m)

Relative Response in dB

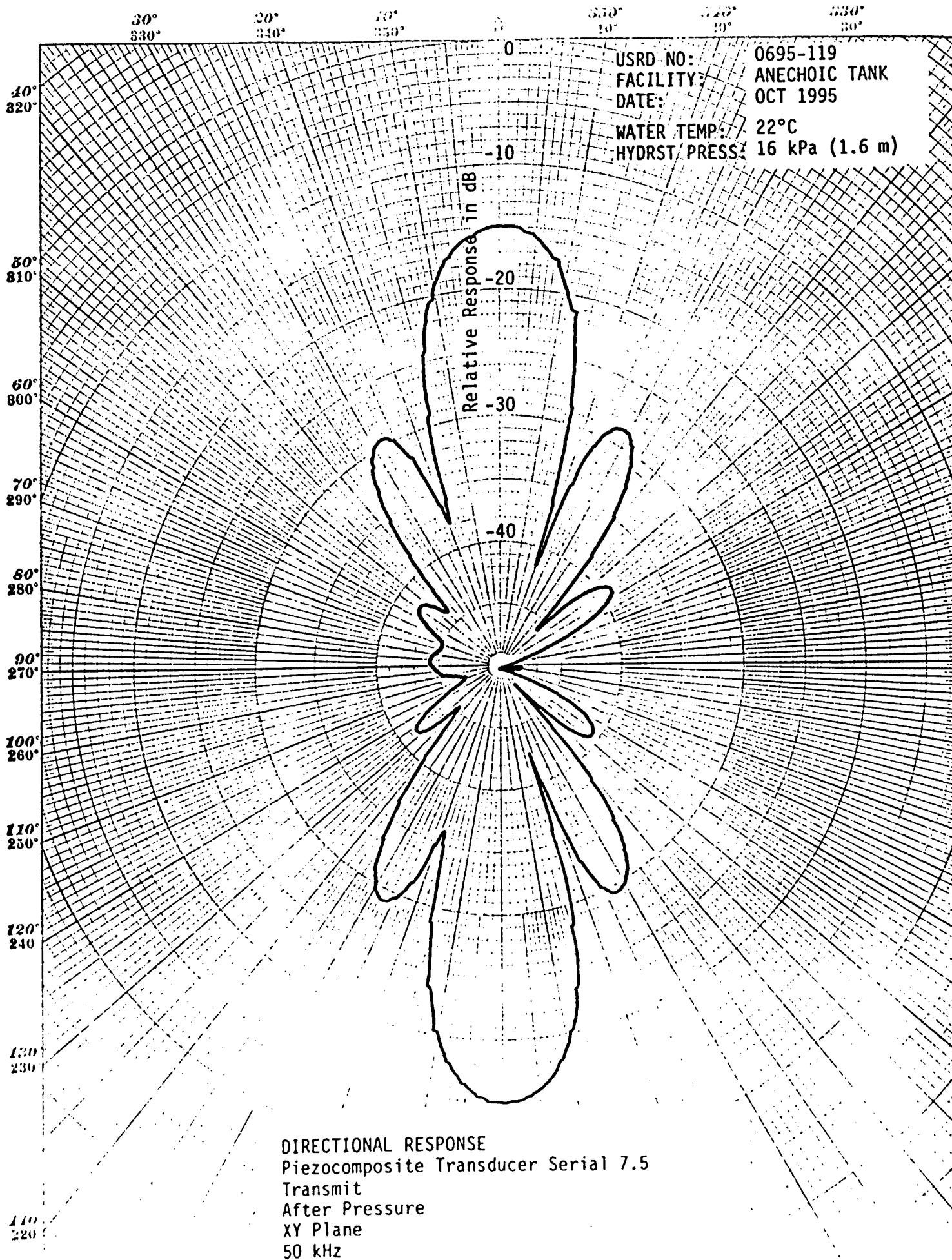
-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
After Pressure  
XY Plane  
20 kHz



12

30°  
330°20°  
340°10°  
350°0°  
10°330°  
19°320°  
30°

USRD NO: 0695-120  
FACILITY: ANECHOIC TANK  
DATE: OCT 1995  
WATER TEMP: 22°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

0

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 7.5  
Transmit  
After Pressure  
XY Plane  
100 kHz

## COORDINATE SYSTEM FOR TRANSDUCER OR PANEL ORIENTATION

The left-handed coordinate system in the sketch below is affixed to the transducer or panel and moves with it, regardless of its physical position. The angle  $(\theta, \phi)$  denotes the direction of sound propagation. Measurements are made with sound propagated parallel to the positive X axis ( $\theta = 90^\circ$ ,  $\phi = 0^\circ$ ) unless otherwise specified.

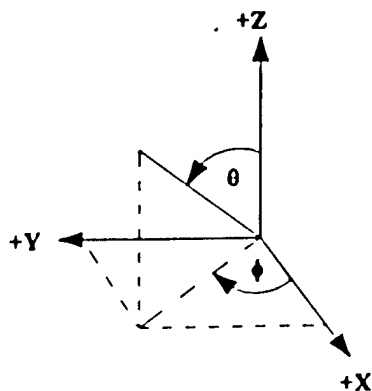
For some measurements, the position of an auxiliary transducer may be specified in terms of cartesian coordinates X, Y, and Z.

Transducers and panels are oriented as follows

ACOUSTIC SURFACE	ORIENTATION
Cylinder	The cylindrical axis is the Z axis; a reference mark for the +Z direction and for another axis is specified.
Plane	The plane or piston face is in the YZ plane, with the X axis normal to the face at the geometric center. A reference mark in the YZ plane is specified.
Sphere	Points on the surface for any two of the three axes are specified.
Other	A sketch of non-conforming configurations is provided.

**Directional Response Patterns: Unless otherwise specified, the following apply**

SPECIFIED PLANE	AXIS OF ROTATION	POSITION OF AXES OR DIRECTIONS ON POLAR PLOTS				
		+ X AXIS	+Y AXIS	+Z AXIS	$\theta = 45^\circ$ $\phi = 90^\circ$	$\theta = 45^\circ$ $\phi = 270^\circ$
XY	Z	0°	90° CW	Upward	—	—
XZ	Y	0°	Downward	90° CW	—	—
YZ	X	Upward	0°	90° CW	—	—
Roll	$\theta = 45^\circ$ $\phi = 270^\circ$	0°	—	—	90° CW	Upward



Origin is at assumed acoustic center of transducer or panel



# Appendix D





DEPARTMENT OF THE NAVY  
NAVAL UNDERSEA WARFARE CENTER  
1176 HOWELL STREET  
NEWPORT RI 02841-1708



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P O BOX 568337  
ORLANDO FL 32856-8337

IN REPLY REFER TO:

3965

Ser X72500-0727

5 APR 1996

USRD CALIBRATION MEMORANDUM NO. 0727

Subj: MEASUREMENTS ON PIEZOCOMPOSITE TRANSDUCERS SERIALS 4-48, 4-50,  
4-51, 4-10P4, 4-11P4, AND 2D-1

Ref: (a) Fonecon, Mr. T. Howarth of NRL to Ms. A. Barela of NUWC-USRD, 30 Nov 1995  
(b) NUWC-USRD Job Order No. R72511

Encl: (1) USRD Charts 1 through 200 and Table 1  
(2) USRD Drawing 62785

1. Measurements on the subject transducers were made in the Anechoic Tank Facility (ATFAC), Lake Facility (LAFAC), High Frequency Facility (HIFAC), and Shock Tube Facility during the period 22 January through 23 February 1996 as arranged in reference (a). Mr. T. Howarth of the Naval Research Laboratory, Washington, DC was present to specify and assist with the measurements. Funds for this service were provided by reference (b).

2. Free-field voltage sensitivity (FFVS), transmitting voltage response (TVR), and directional response (DR) in the horizontal (XY) plane were measured in the ATFAC in the frequency range 2 to 200 kHz, at the water temperatures 4 and 22°C, and at hydrostatic pressures to 6895 kPa (703.1 m). FFVS, TVR, and DR in the horizontal (XY) plane were measured in the LAFAC in the frequency range 1 to 200 kHz, at the water temperature 15 and 18°C, and at the depth of 3.9 m (38 kPa). FFVS and TVR were measured in the HIFAC in the frequency range 200 to 400 kHz, at the water temperature 18°C, and at the depth of 0.6 m (5.8 kPa). Conditions and results of these measurements are presented in enclosure (1).

3. Piezocomposite transducers serials 4-50 and 4-11P4 were observed to perform intermittently at the water temperature 22°C, and at the hydrostatic pressure of 6895 kPa (703.1 m).

4. A shock test was performed that was comparable to shot #4 of the heavyweight shock test of Mil-S-901D. Chart 200 of enclosure (1) shows the actual shock pressure profile that was used for this test.

Further dissemination only as directed by  
Commanding Officer, Naval Undersea  
Warfare Center ( 5 APR 1996 ) or  
higher DoD authority.

3965  
Ser X72500-0727  
5 APR 1996

USRD CALIBRATION MEMORANDUM NO. 0727

5. Orientation was as described for a piston in enclosure (2). An arrow on the face of the transducer was in the direction of the +Z axis and the cable exited in the -X direction except where otherwise noted.



A. R. GARCEAU  
Project Leader



R. M. DRAKE  
Head, Acoustic Measurements T&E Branch

Copy to:

NRL (Code 7135, T. Howarth) (4)  
NUWC-USRD (Code 251, R. Ting)  
(Code 2582)  
(Code 2572, K. Benjamin)

TABLE 1  
DATA DIRECTORY  
Piezocomposite Transducers

	CHART
<u>ATFAC</u>	
Serial 4-48	
4°C	
FFVS .....	1
TVR .....	2
DR .....	3-18
22°C	
FFVS .....	19
TVR .....	20
DR .....	21-36
Serial 4-50	
4°C	
FFVS .....	37
TVR .....	38
DR .....	39-54
22°C	
FFVS .....	55
TVR .....	56
DR .....	57-72
Serial 4-51	
4°C	
FFVS .....	73
TVR .....	74
DR .....	75-90
22°C	
FFVS .....	91
TVR .....	92
DR .....	93-108

TABLE 1

	CHART
<b>Serial 4-10P4</b>	
4°C	
FFVS .....	109
TVR .....	110
DR .....	111-126
22°C	
FFVS .....	127
TVR .....	128
DR .....	129-144
<b>Serial 4-11P4</b>	
4°C	
FFVS .....	145
TVR .....	146
DR .....	147-162
22°C	
FFVS .....	163
TVR .....	164
DR .....	165-177
<b><u>LAFAC and HIFAC</u></b>	
<b>Serial 2D-1</b>	
FFVS .....	178
TVR .....	179
DR .....	180-183
<b>Serial 4-48</b>	
FFVS .....	184
TVR .....	185
DR, Pre-Shock .....	186-189
DR, Post-Shock .....	190-193
<b>Serial 4-50</b>	
FFVS .....	194
TVR .....	195
DR .....	196-199
<b><u>SHOCK TUBE FACILITY</u></b>	
Pressure Waveform .....	200

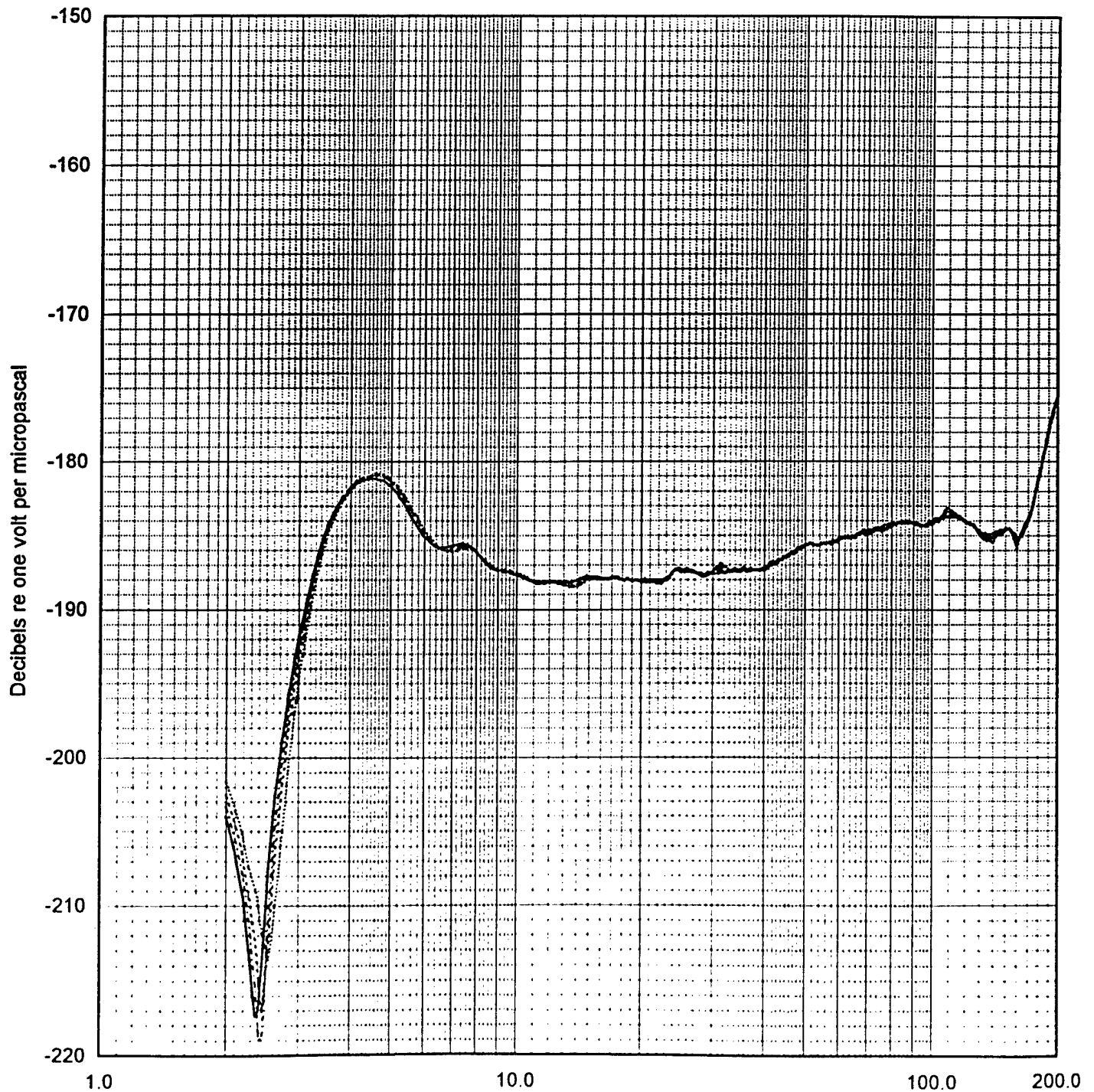
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-48

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
- · - · - 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure





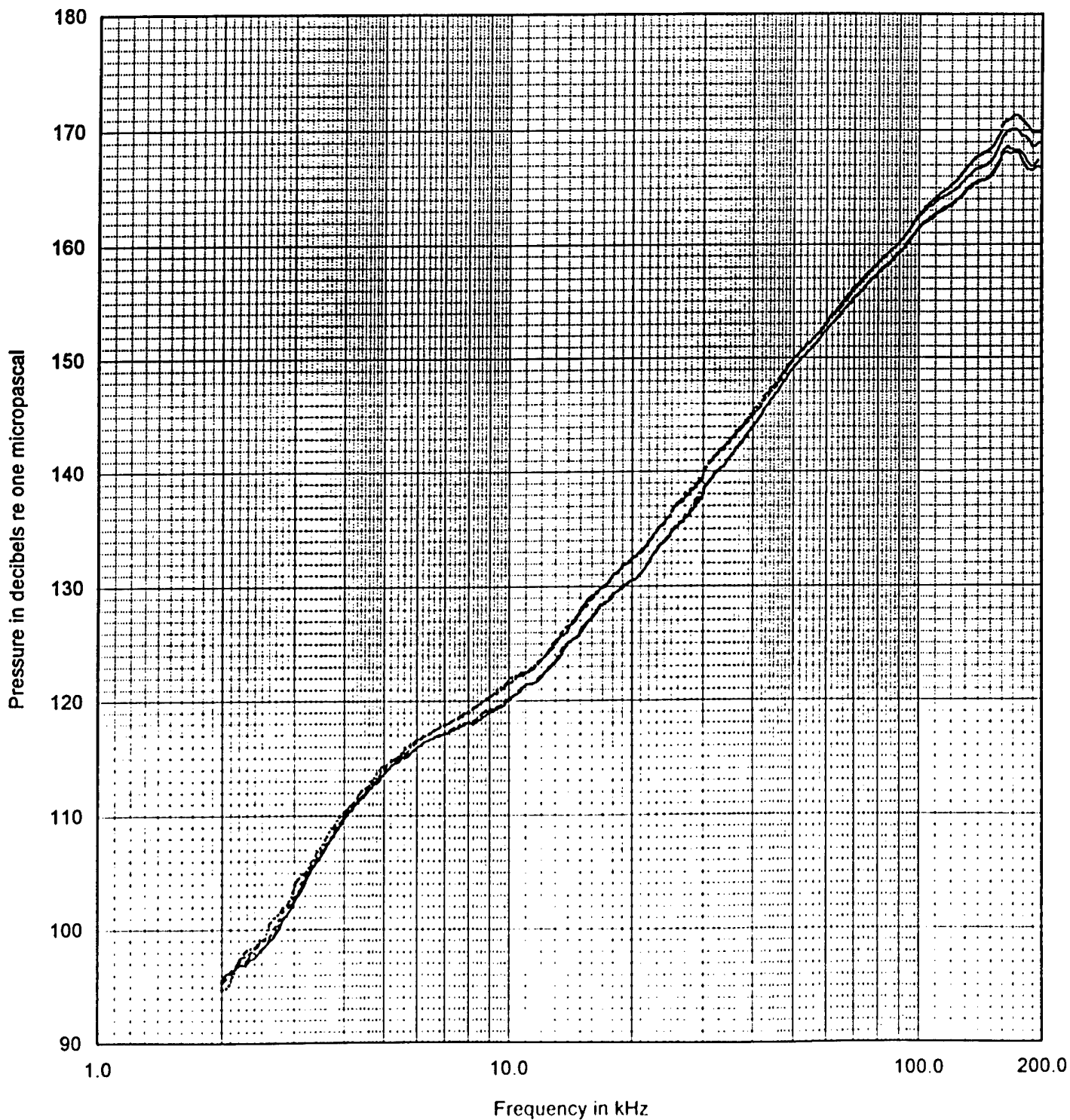
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-48

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

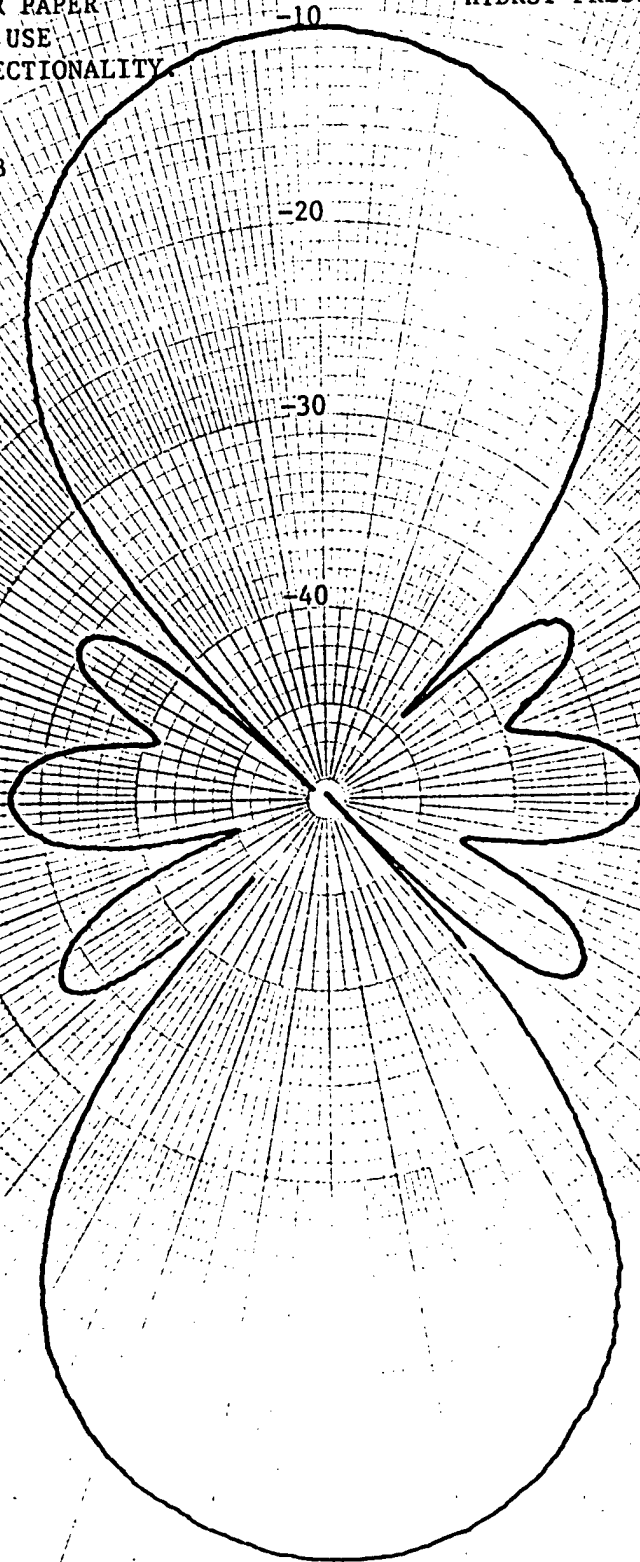
- 16 kPa ( 1.6 m) Before Pressure
- 3448 kPa ( 351.6 m)
- ..... 6895 kPa ( 703.1 m)
- 16 kPa ( 1.6 m) After Pressure



NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-4  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)



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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
Before Pressure  
XY Plane  
20 kHz

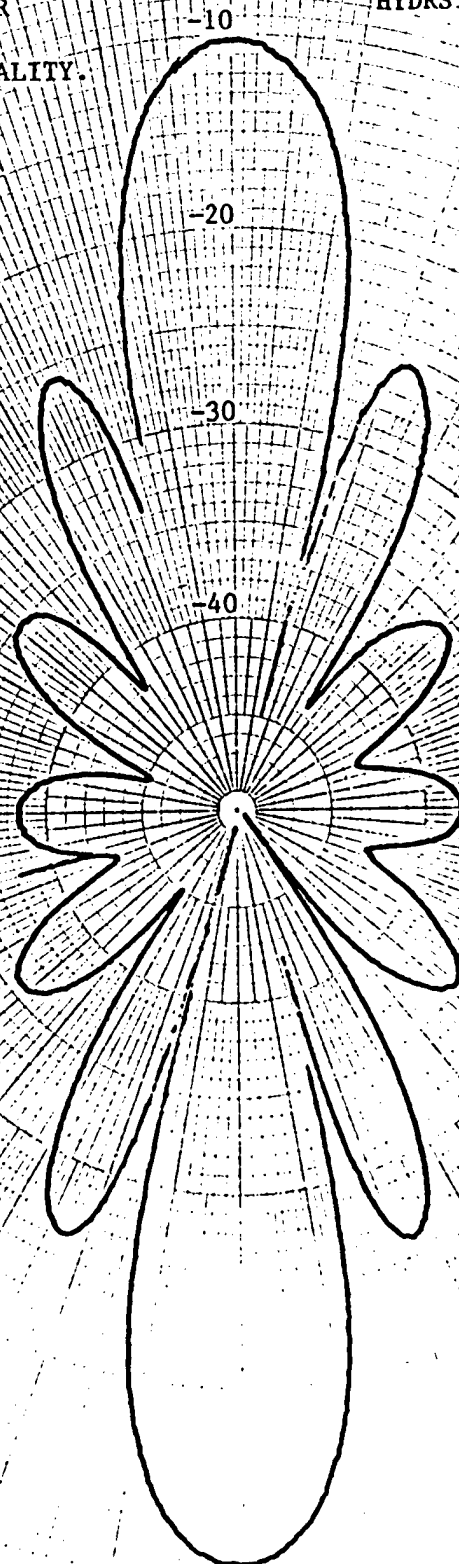
NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-5  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit Before Pressure  
XY Plane  
50 kHz



30° 20° 10° 0° 10° 20° 30°  
330° 340° 350° 360° 370° 380° 390°

USRD NO: 0727-6  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

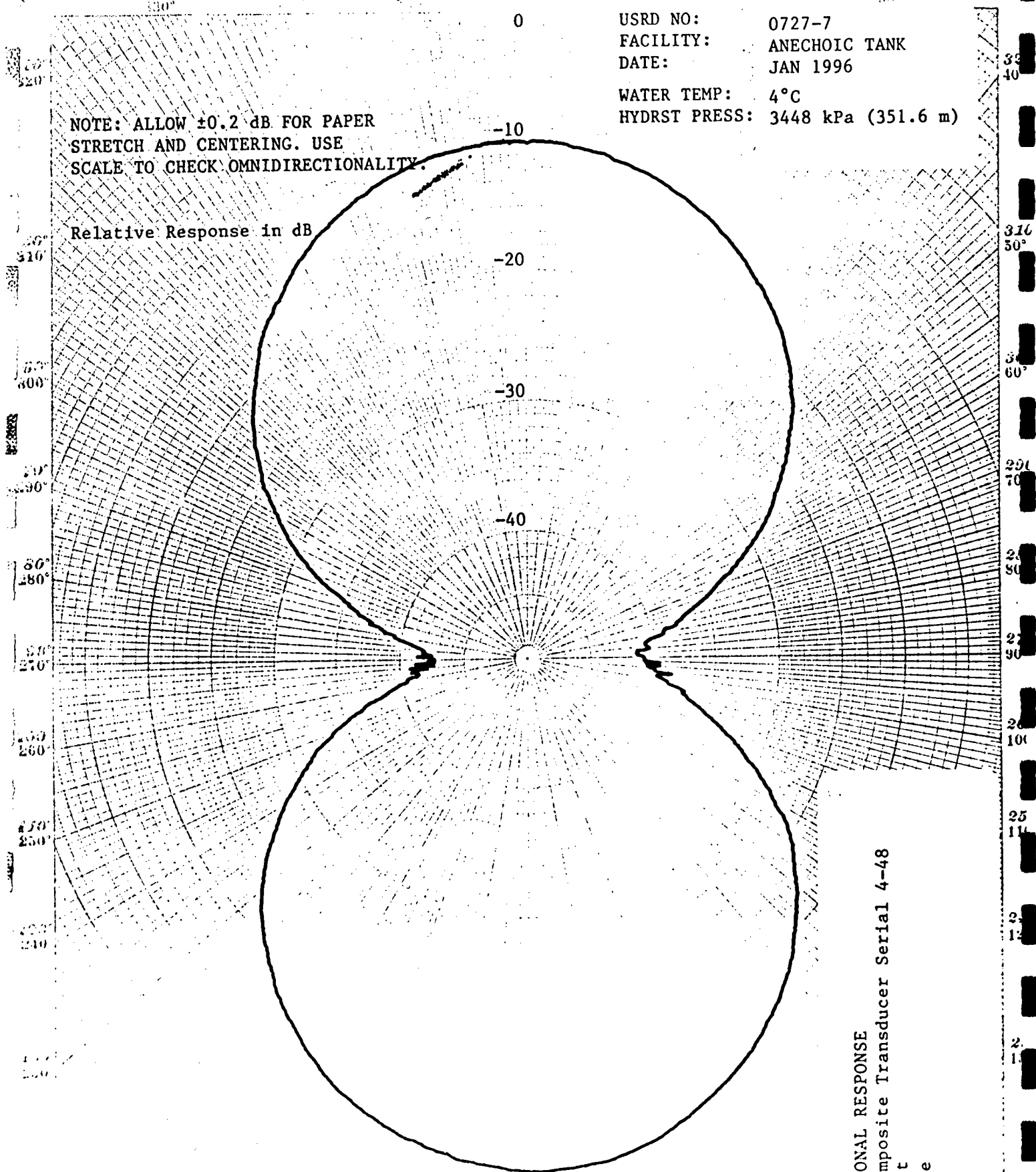
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
Before Pressure  
XY Plane  
100 kHz

USRD NO: 0727-7  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
XY Plane  
10 kHz

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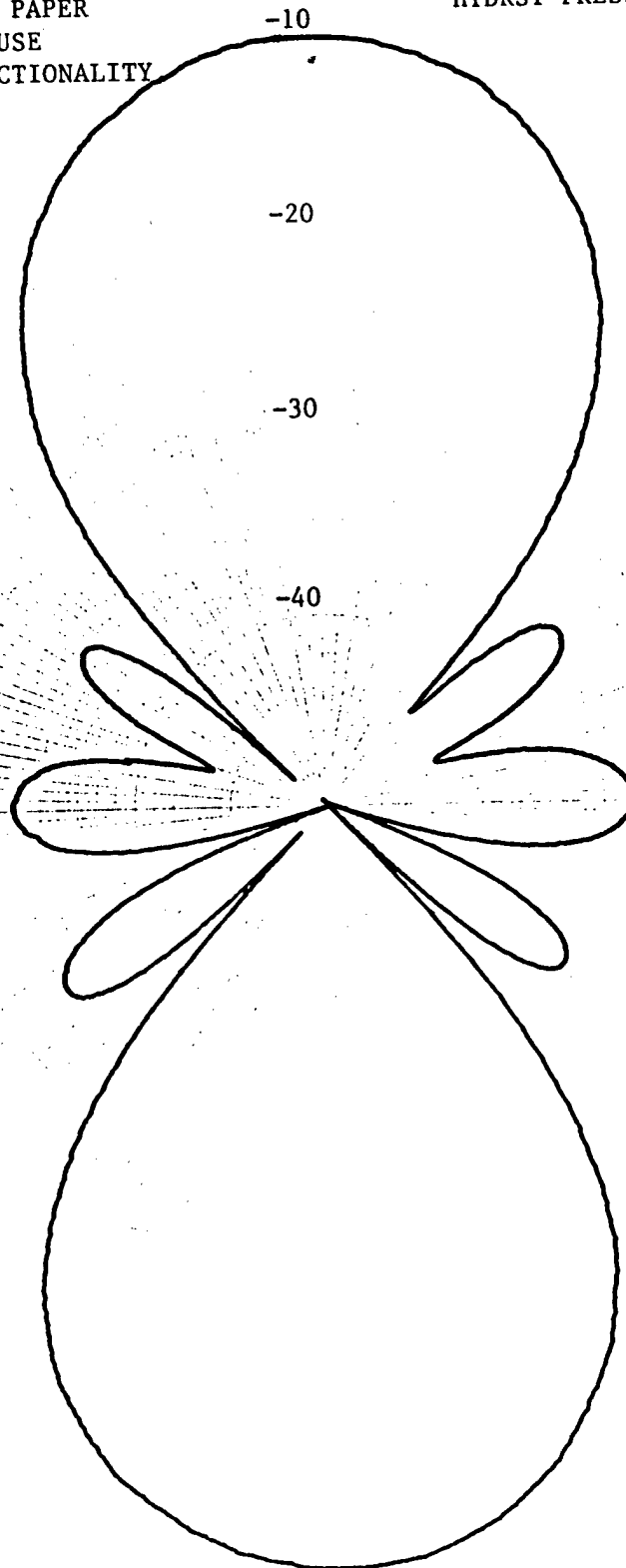


0

USRD NO: 0727-8  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
XY Plane  
20 kHz

24

30° 20° 10° 0° 350° 340° 330° 320° 310° 300° 290° 280° 270° 260° 250° 240° 230° 220° 210° 200° 190° 180° 170° 160° 150°

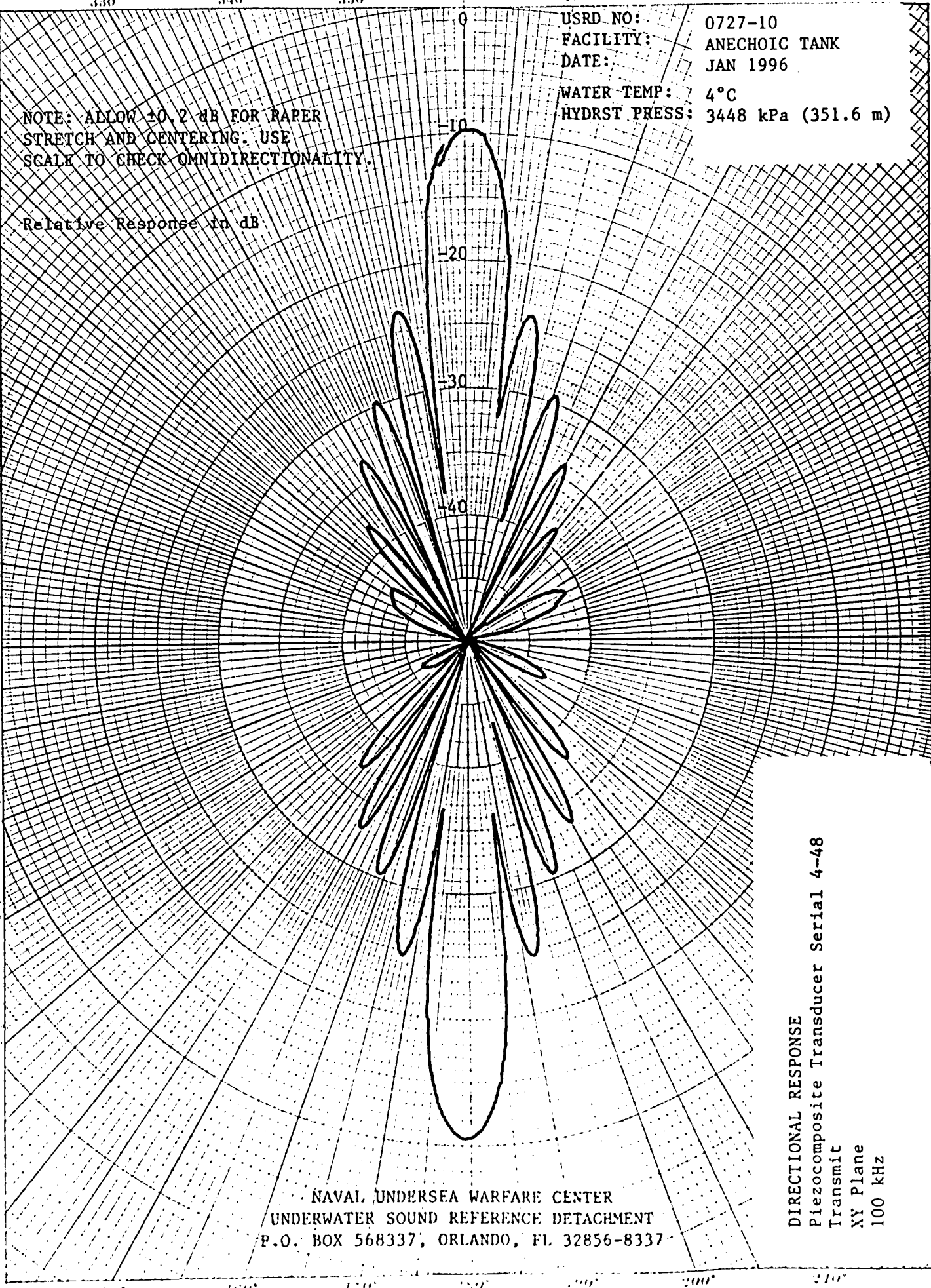
USRD NO: 0727-10  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW ±0.2 dB FOR PAPER STRETCH AND CENTERING. USE SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

0° 40' 30 320°  
50° 810°  
60° 60' 800°  
70° 290°  
80° 80' 280°  
90° 90' 270°  
100° 100' 260°  
110° 110' 250°  
120° 120' 240°  
130° 230°  
140° 220°

340°  
310° 50°  
300° 60°  
290° 70°  
280° 80°  
270° 90°  
260° 100°  
250° 110°  
240° 120°  
230° 130°  
220° 140°



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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
XY Plane  
100 kHz

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

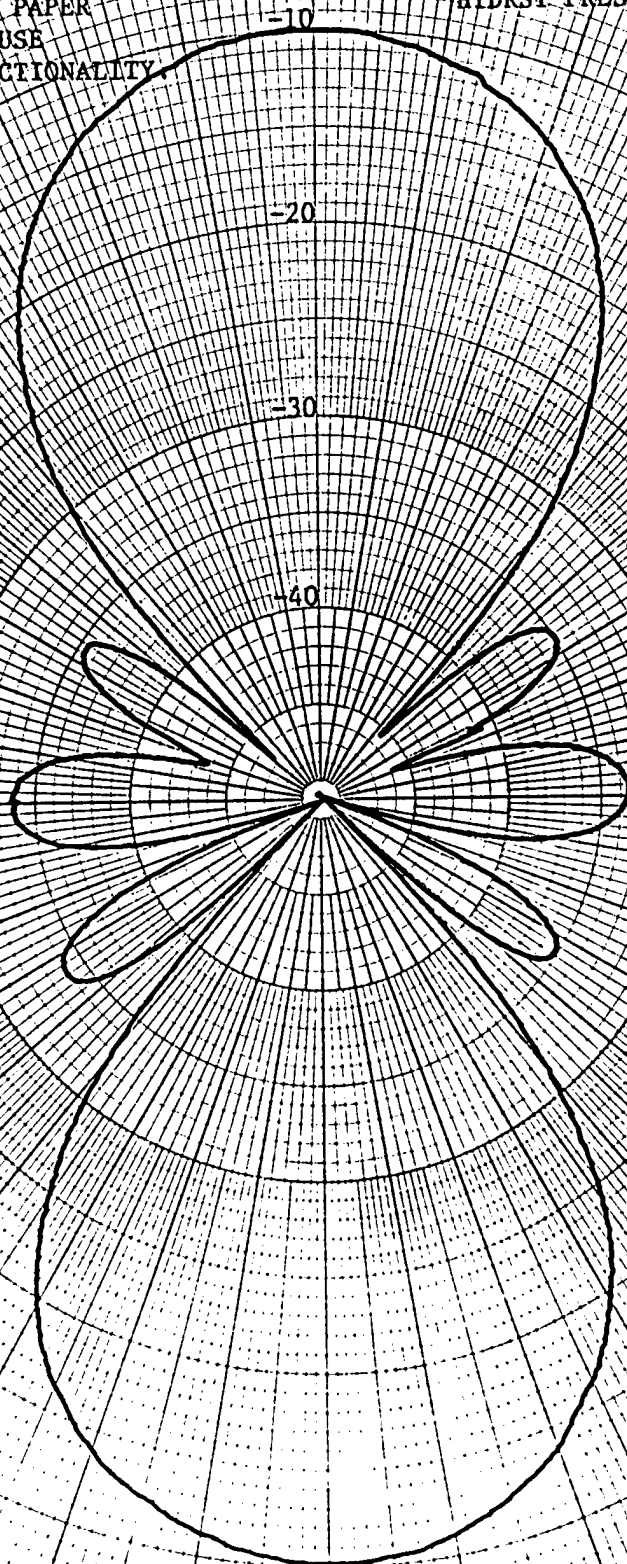
340°  
20°

330°  
30°

USRD NO: 0727-12  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

NOTE: ALLOW 10-12 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
XY Plane  
20 kHz

30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 0° 10° 20° 30°

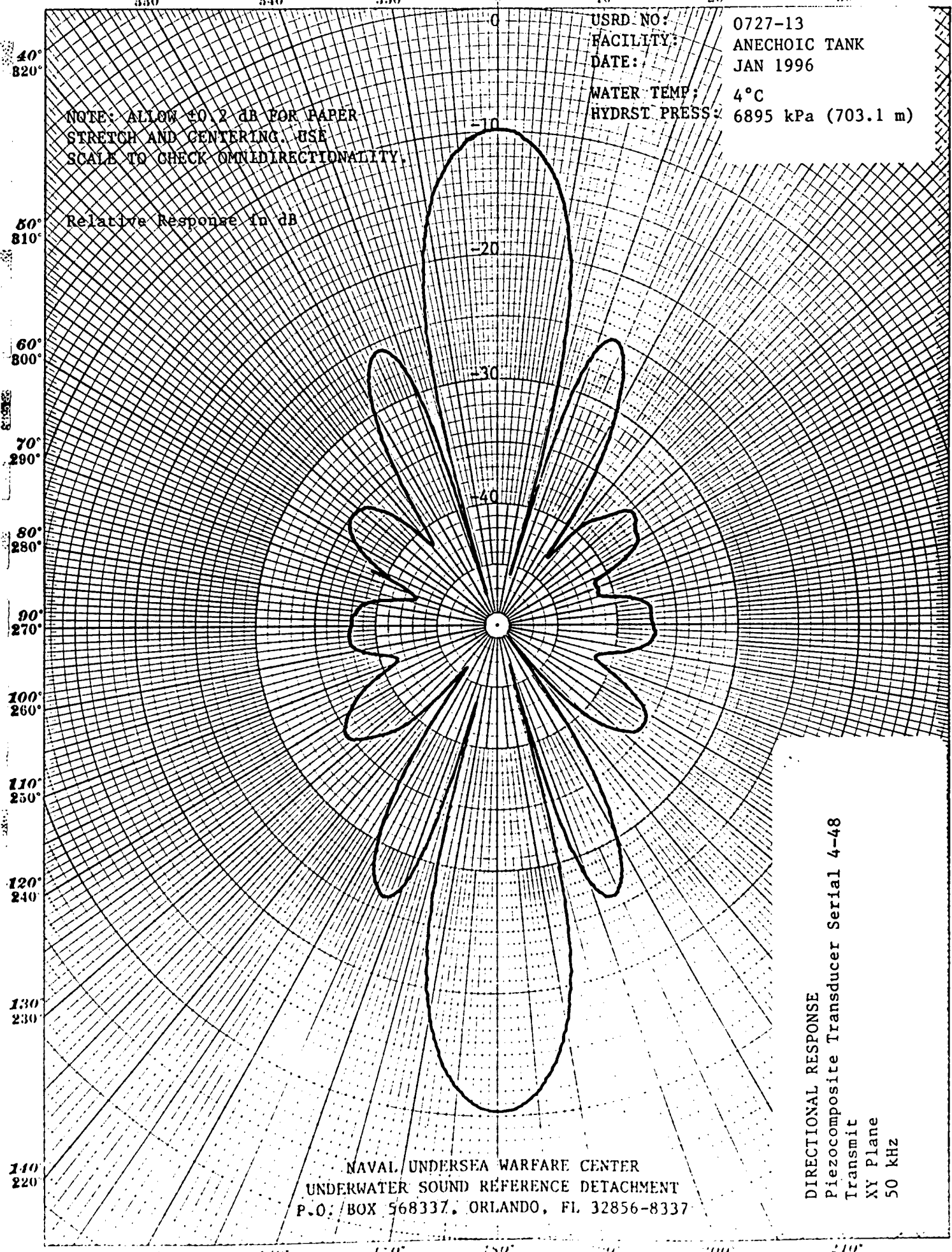
USRD NO: 0727-13  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

40° 820°  
50° 810°  
60° 800°  
70° 790°  
80° 280°  
90° 270°  
100° 260°  
110° 250°  
120° 240°  
130° 230°  
140° 220°

30° 40°  
50°  
60°  
70°  
80°  
90°  
10°  
11°  
12°  
13°  
14°



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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
XY Plane  
50 kHz

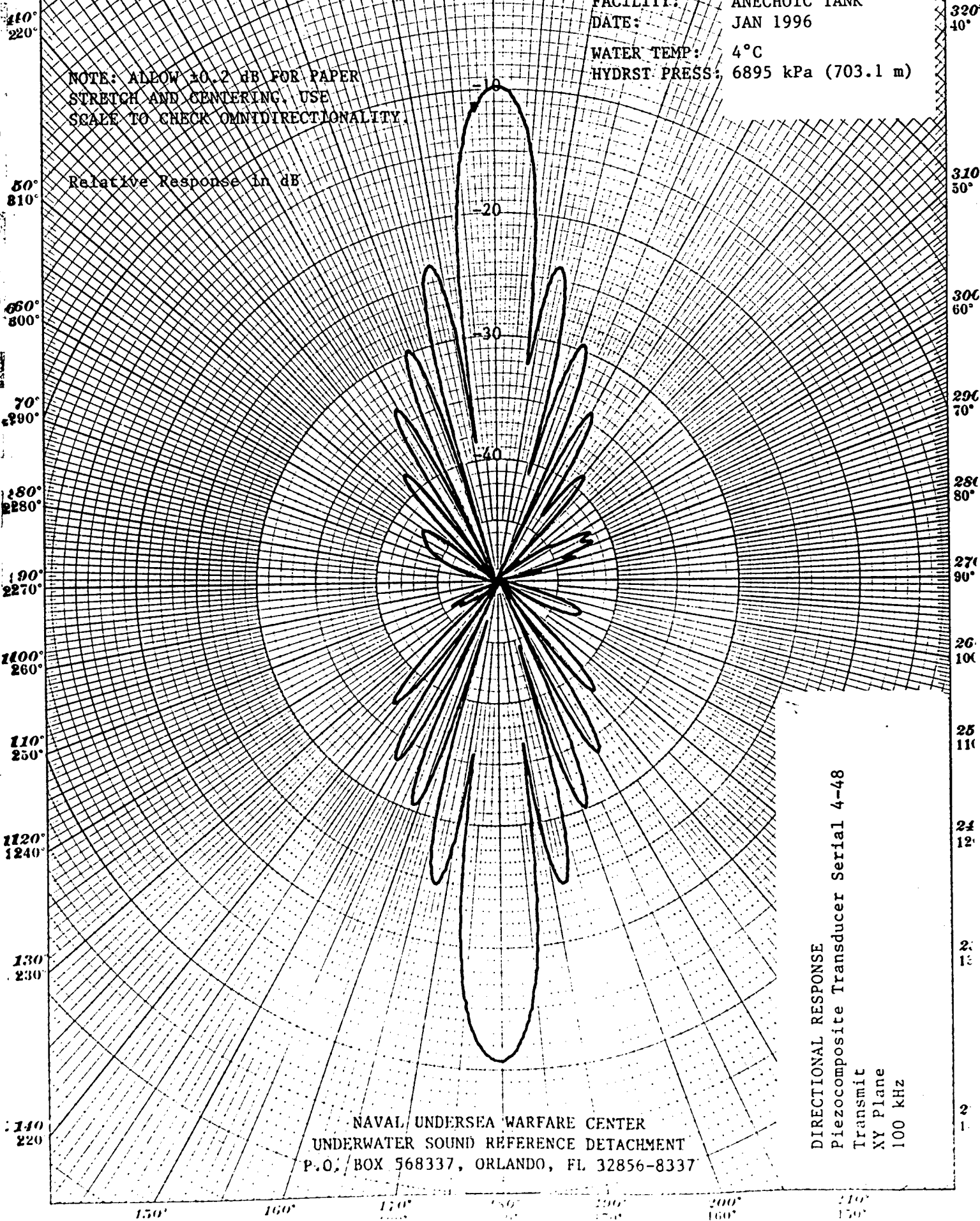
5  
7

30° 20° 10° 0° 350° 340° 330°

USRD NO: 0727-14  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

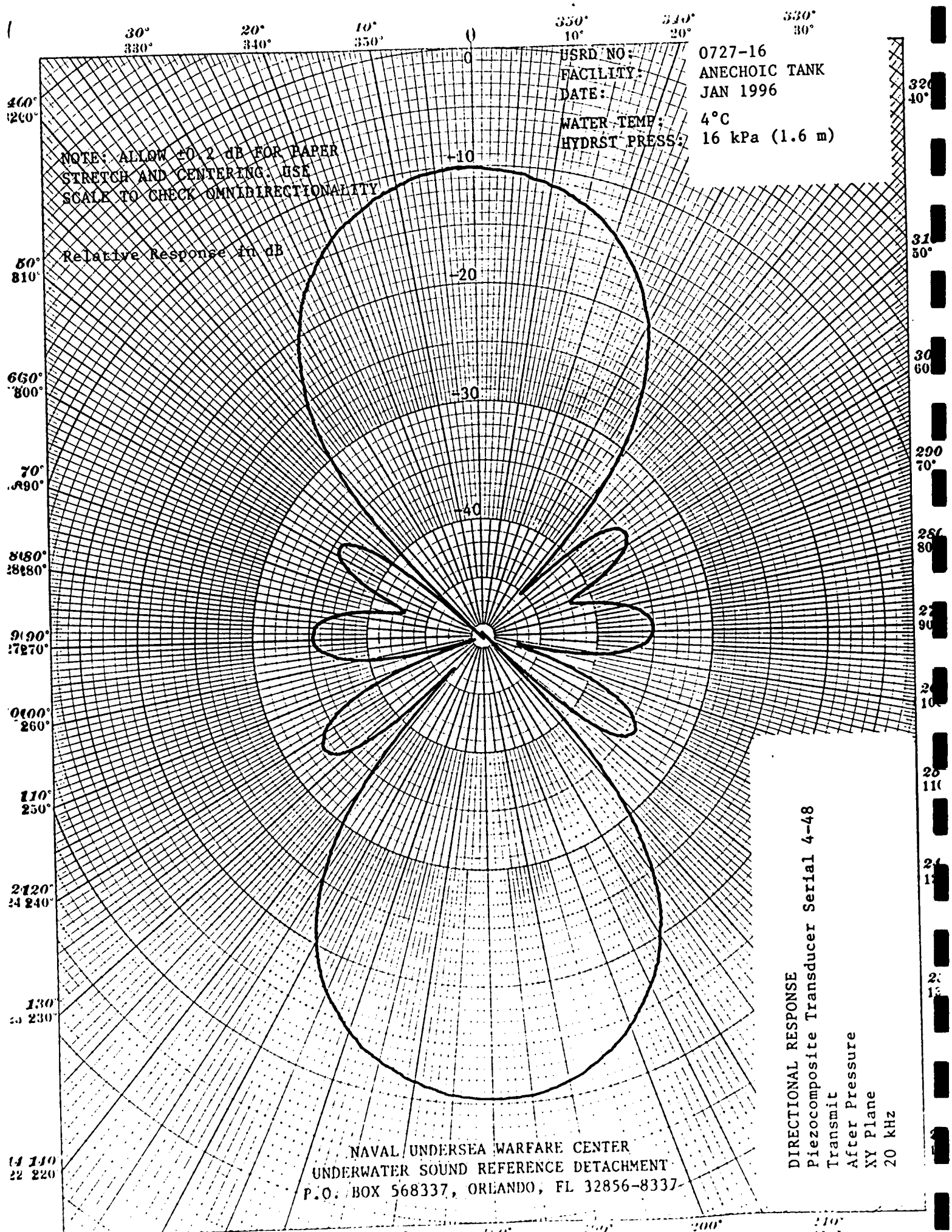
Relative Response in dB



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UNDERWATER SOUND REFERENCE DETACHMENT  
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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
XY Plane  
100 kHz





NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB

USRD NO: 0727-16  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

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UNDERWATER SOUND REFERENCE DETACHMENT  
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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit After Pressure  
XY Plane  
20 kHz

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-18  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

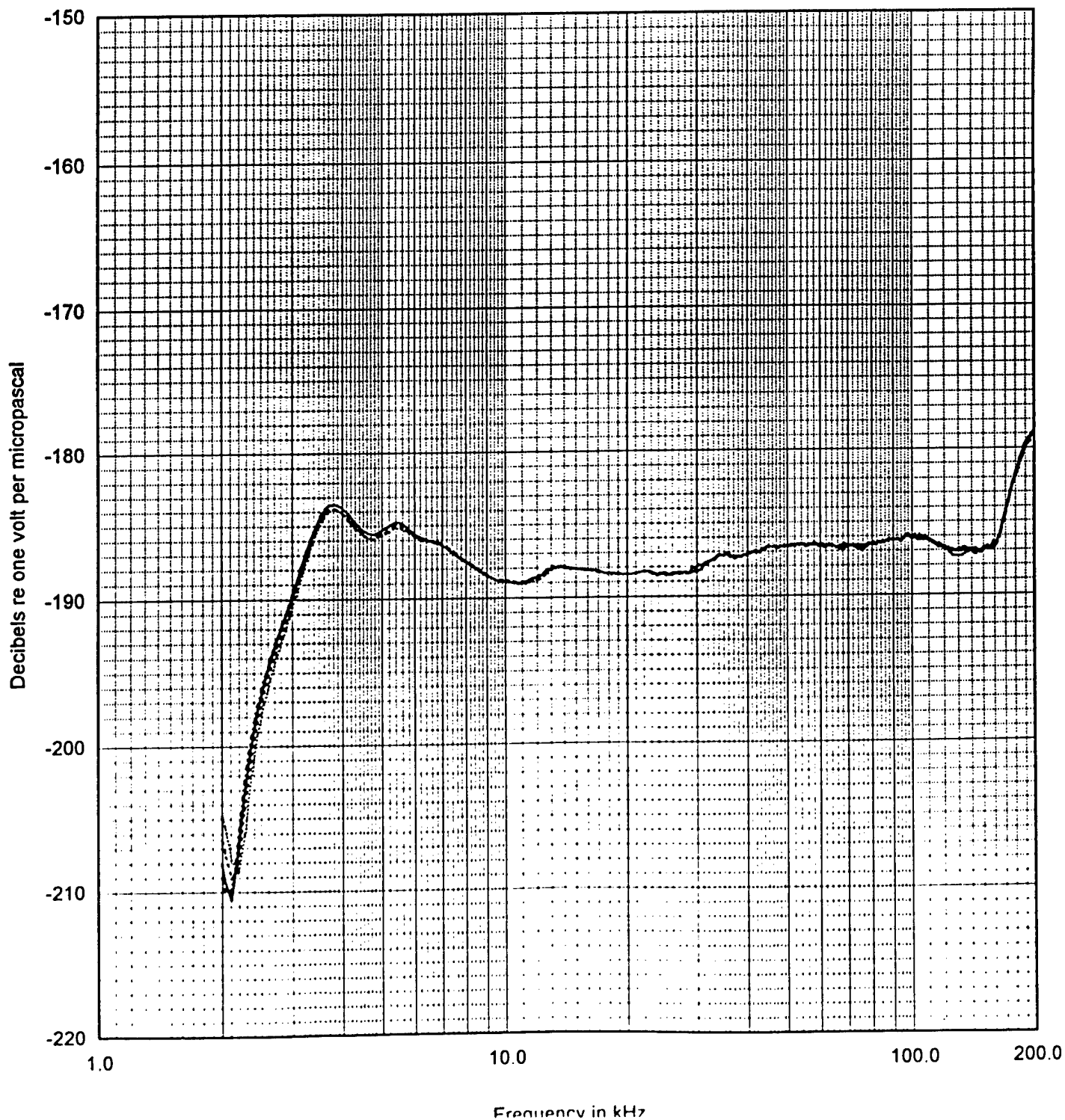
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Transmit  
After Pressure  
XY Plane  
100 kHz

## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-48

Open-circuit voltage measured at end of cable; Unbalanced  
Water Temp: 22° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
- . - . - 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



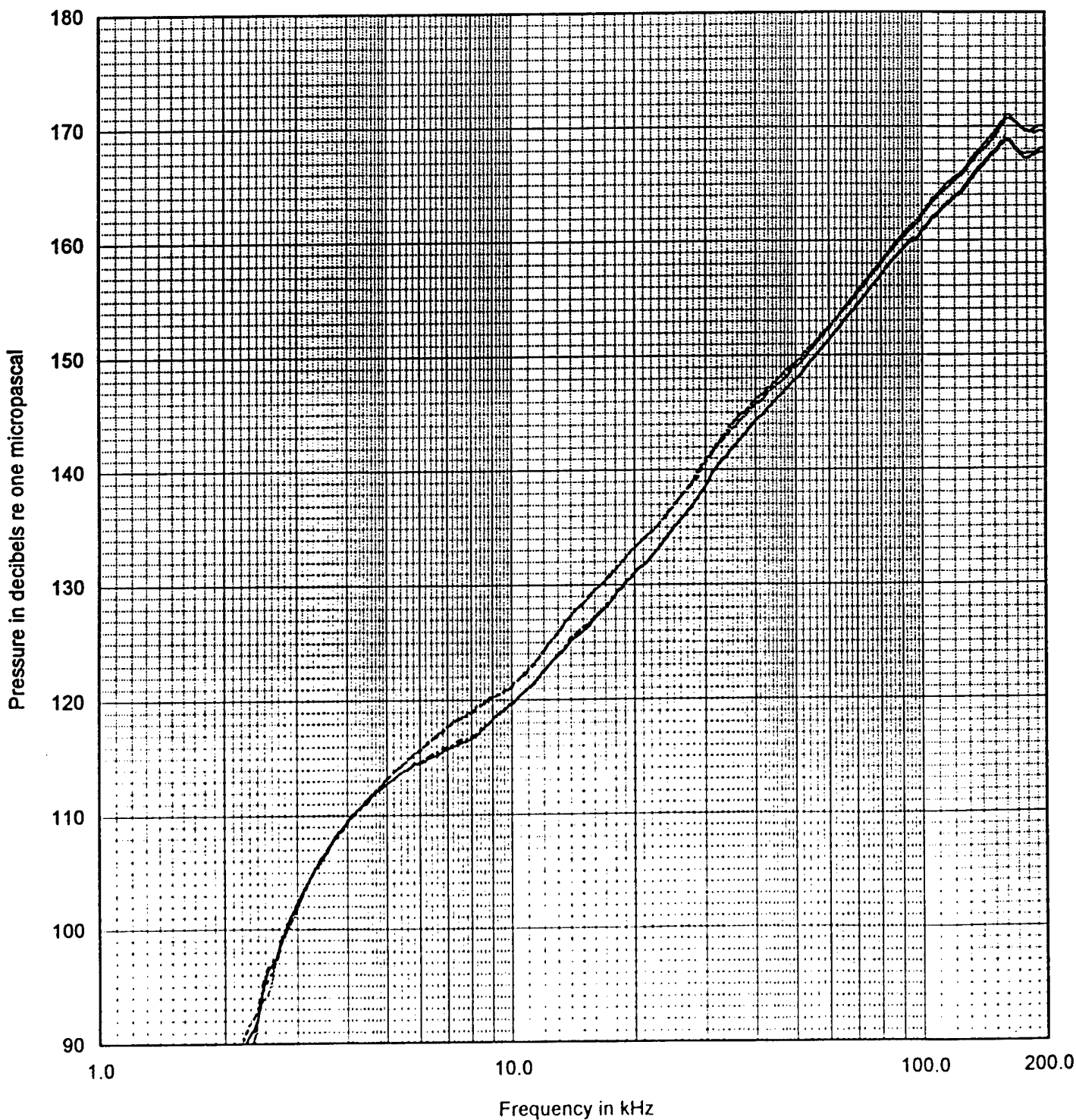
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-48

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

————— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure





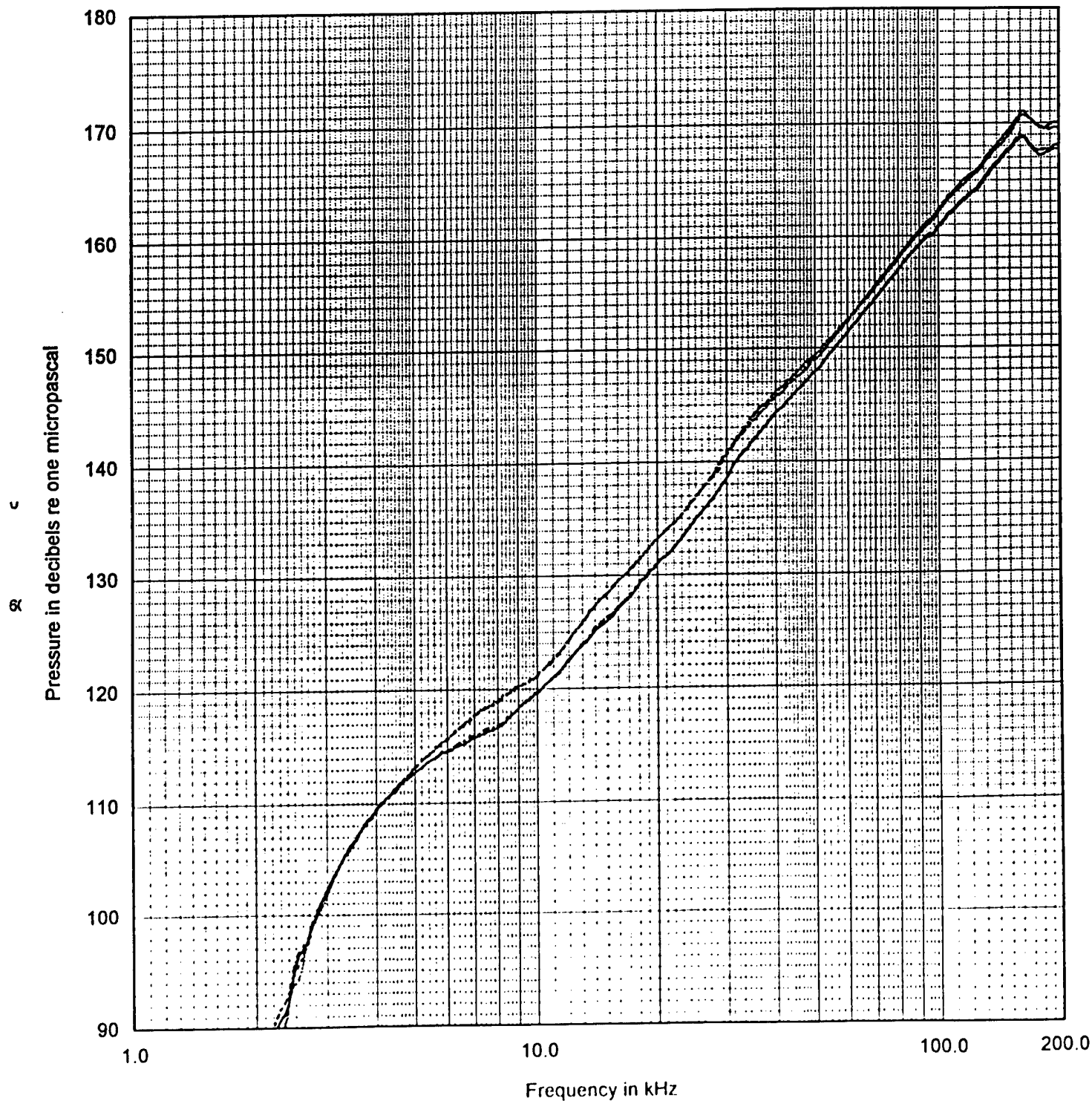
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-48

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- · - · - 16 kPa ( 1.6 m) After Pressure





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USRD NO. 0727-22  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

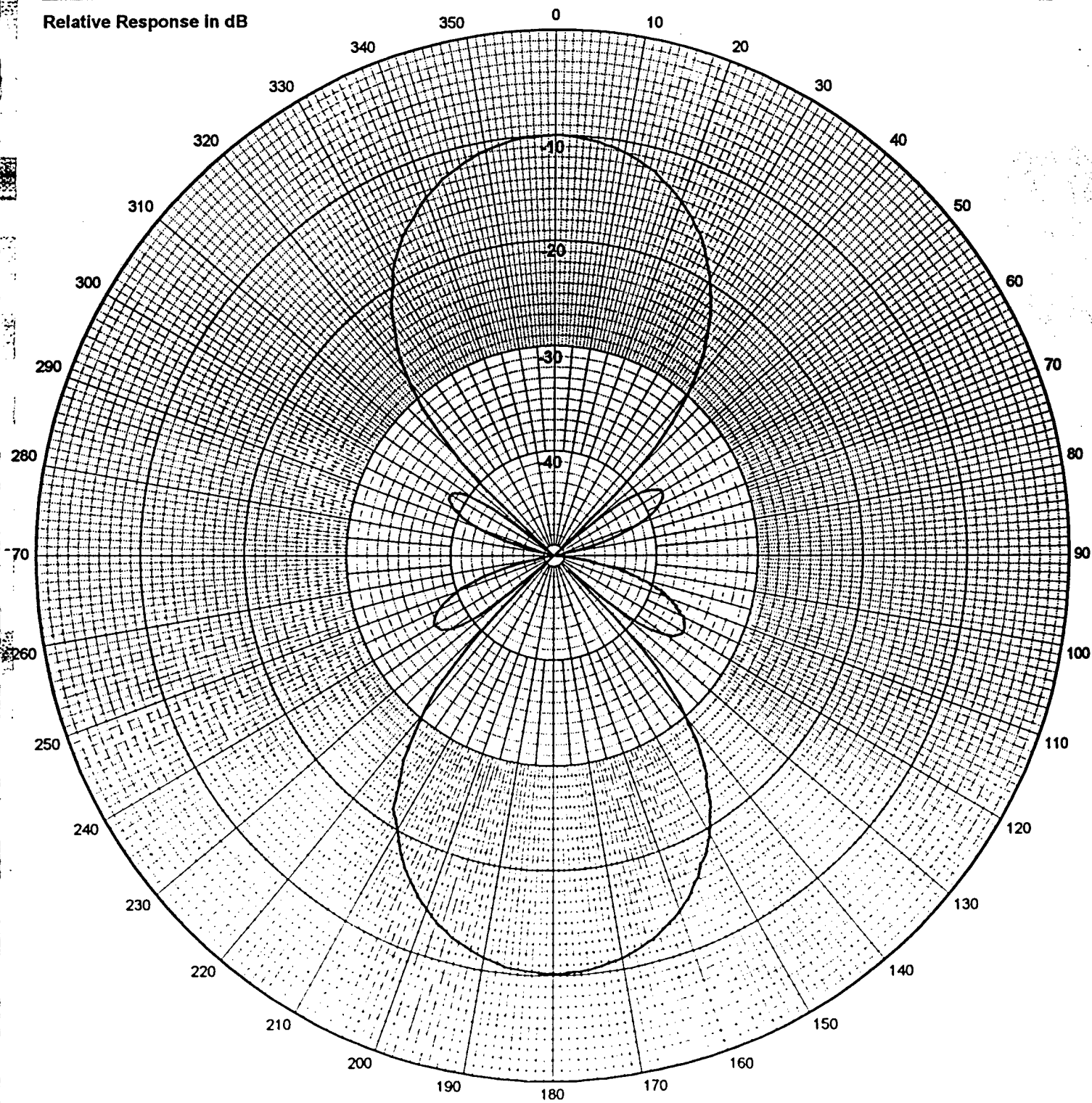
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

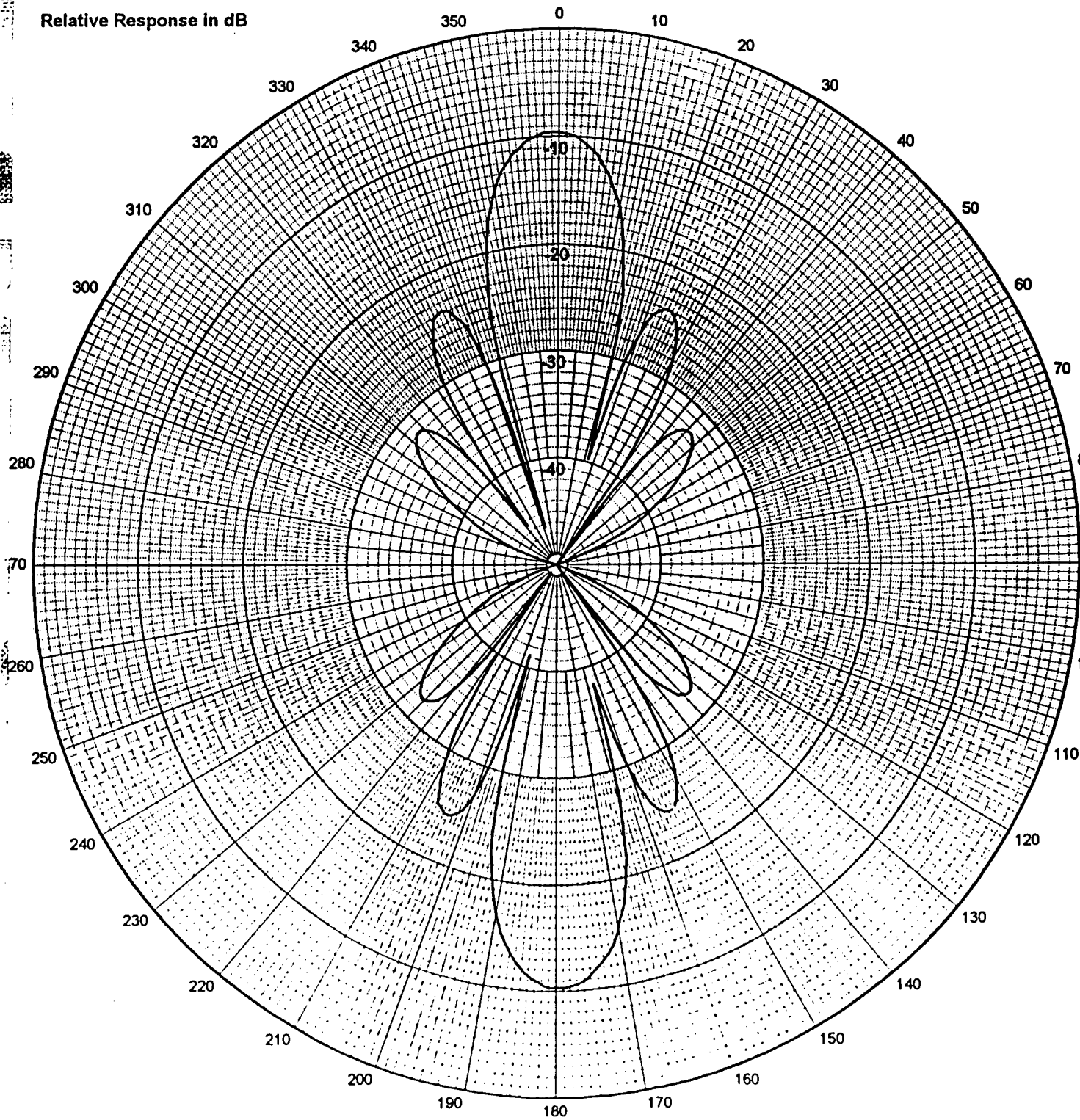
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



Degrees

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-24  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

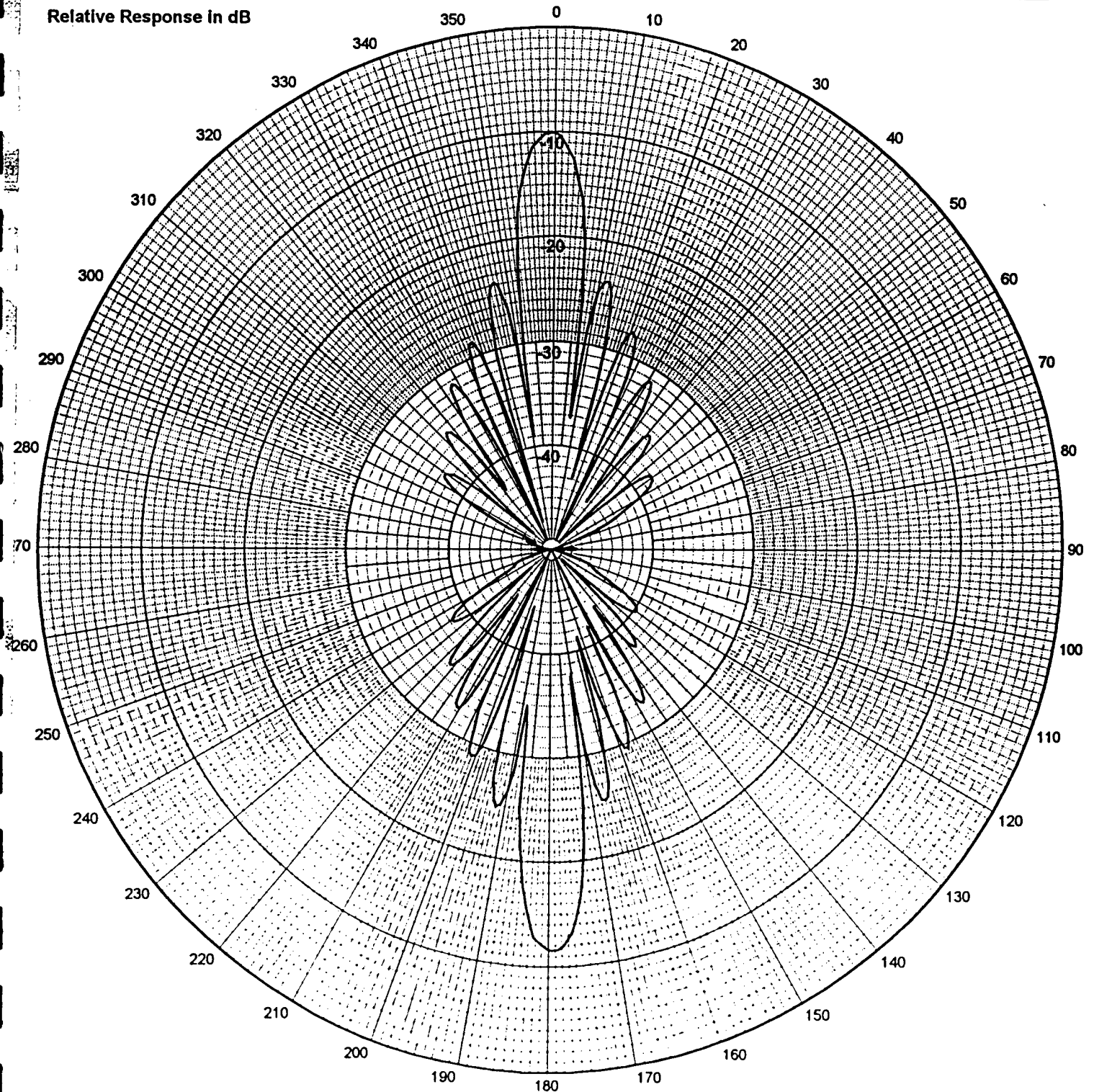
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB



Degrees

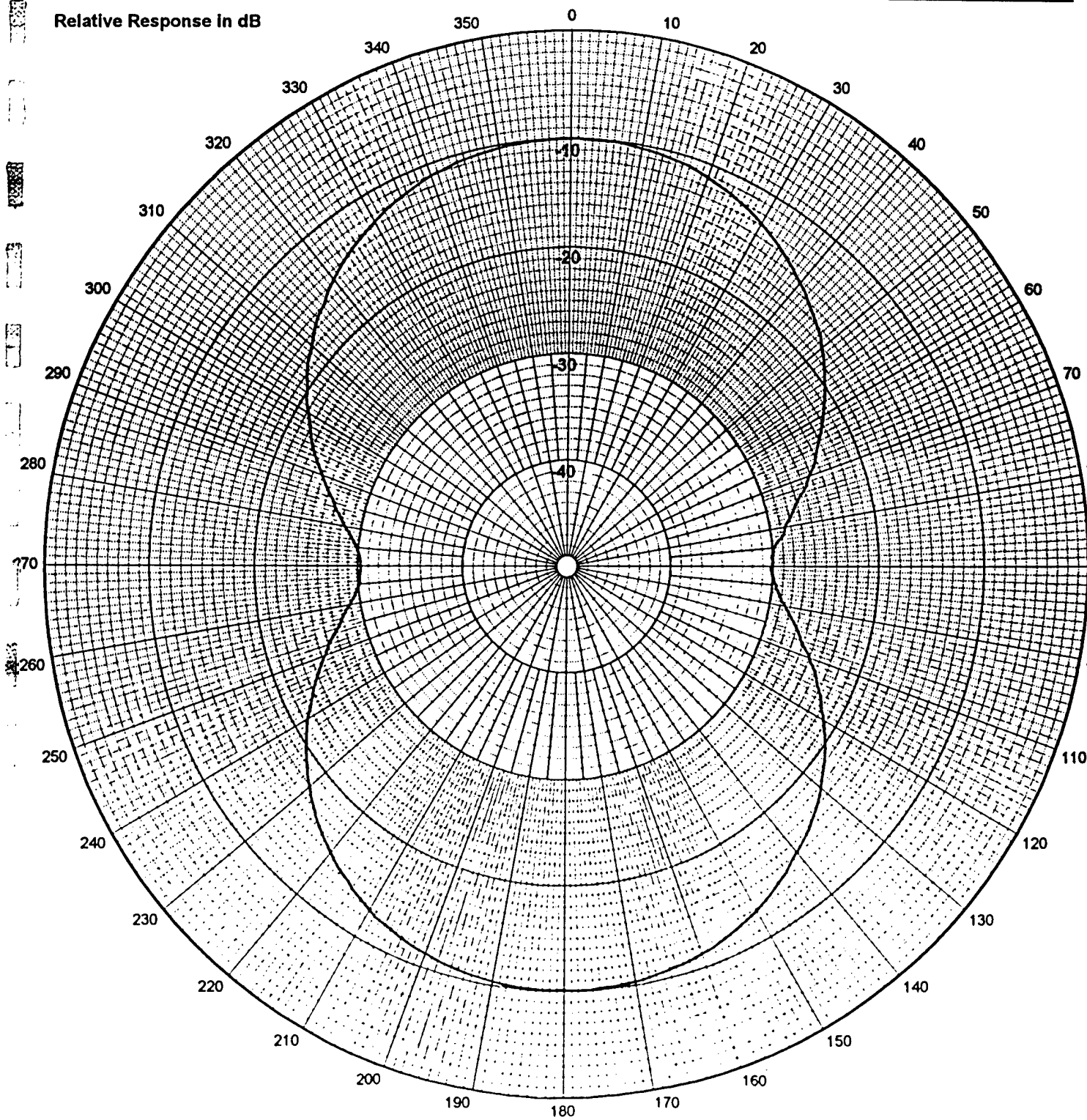
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-25  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response In dB



Degrees

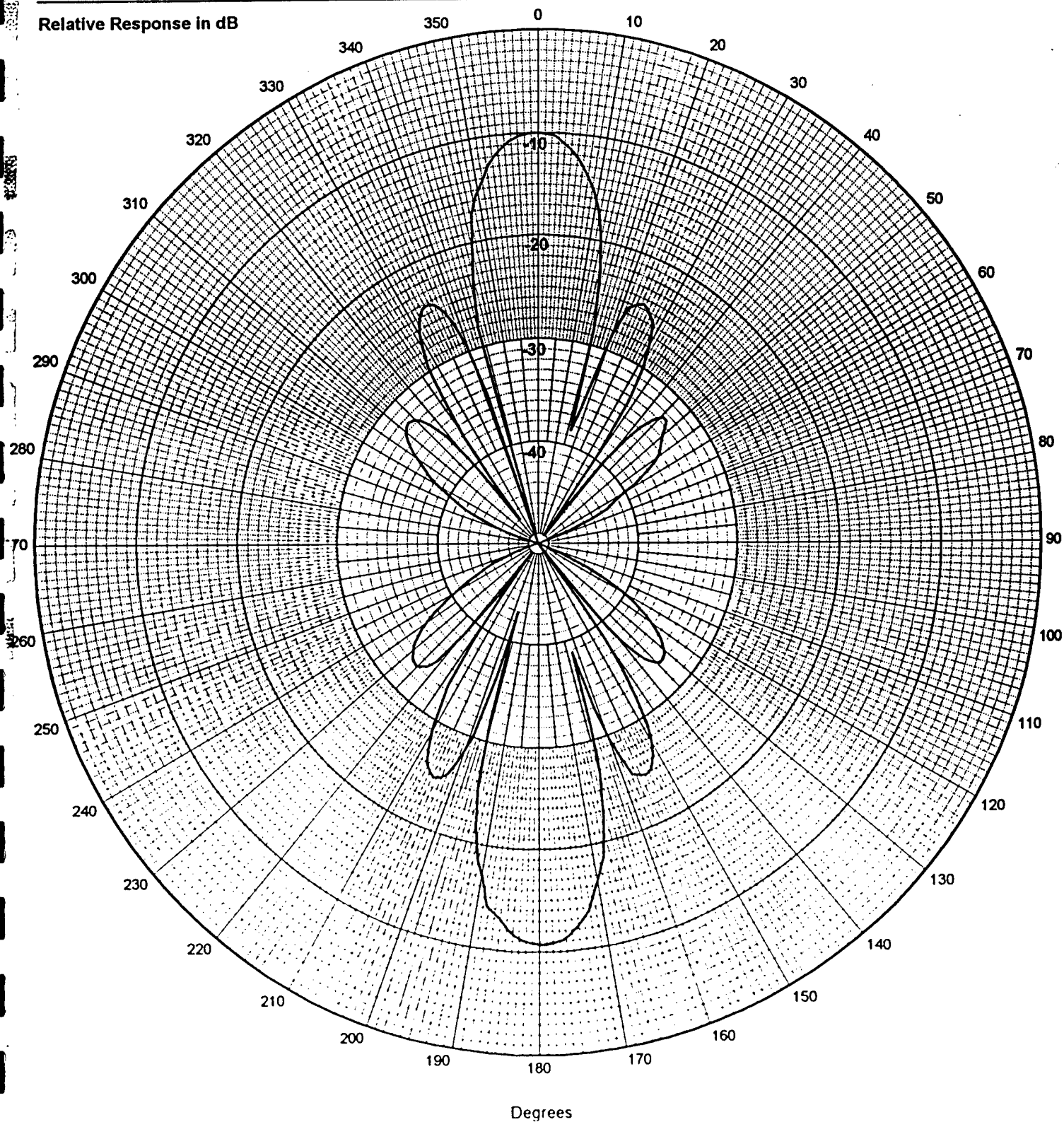
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-27  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

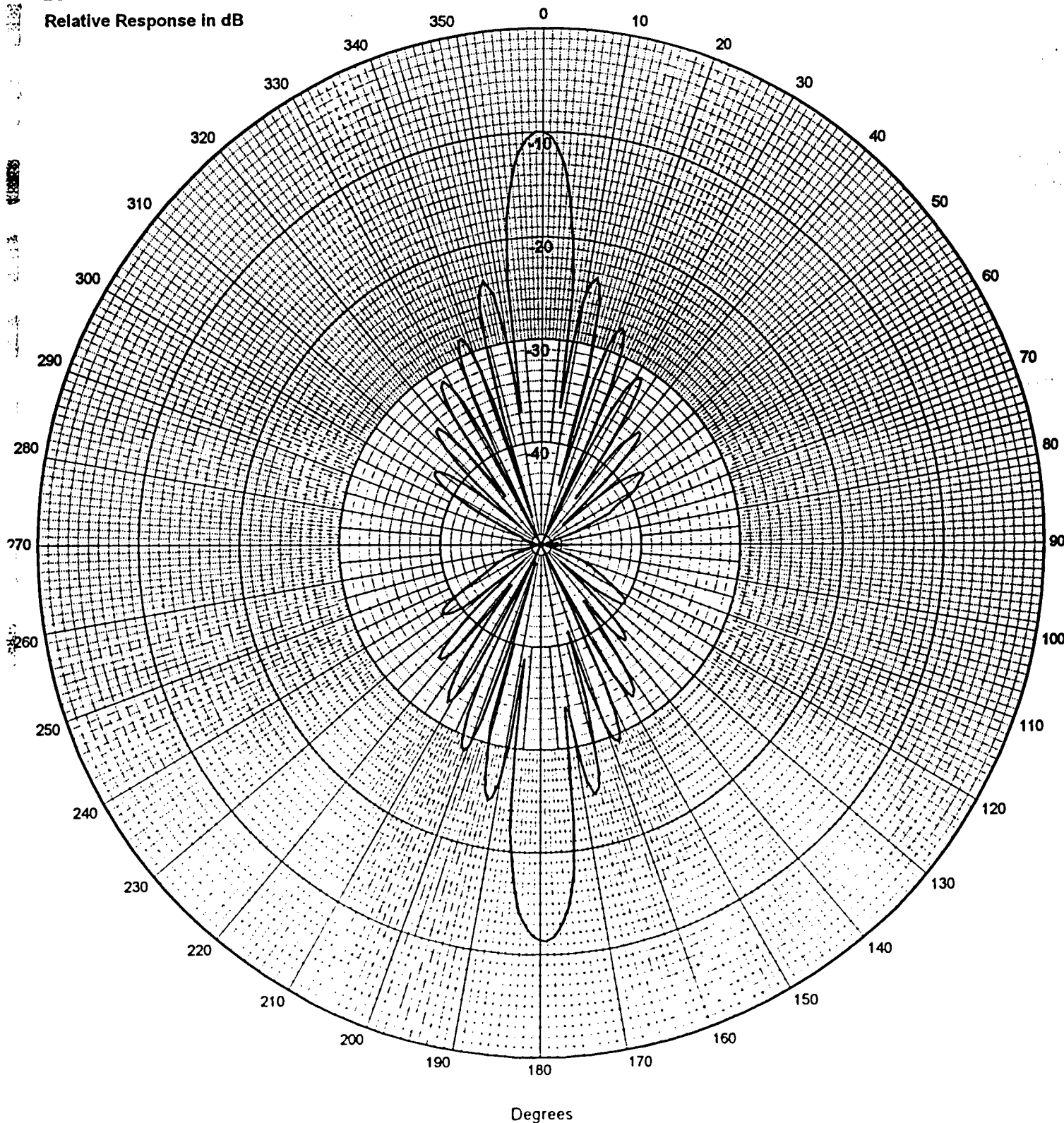
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz



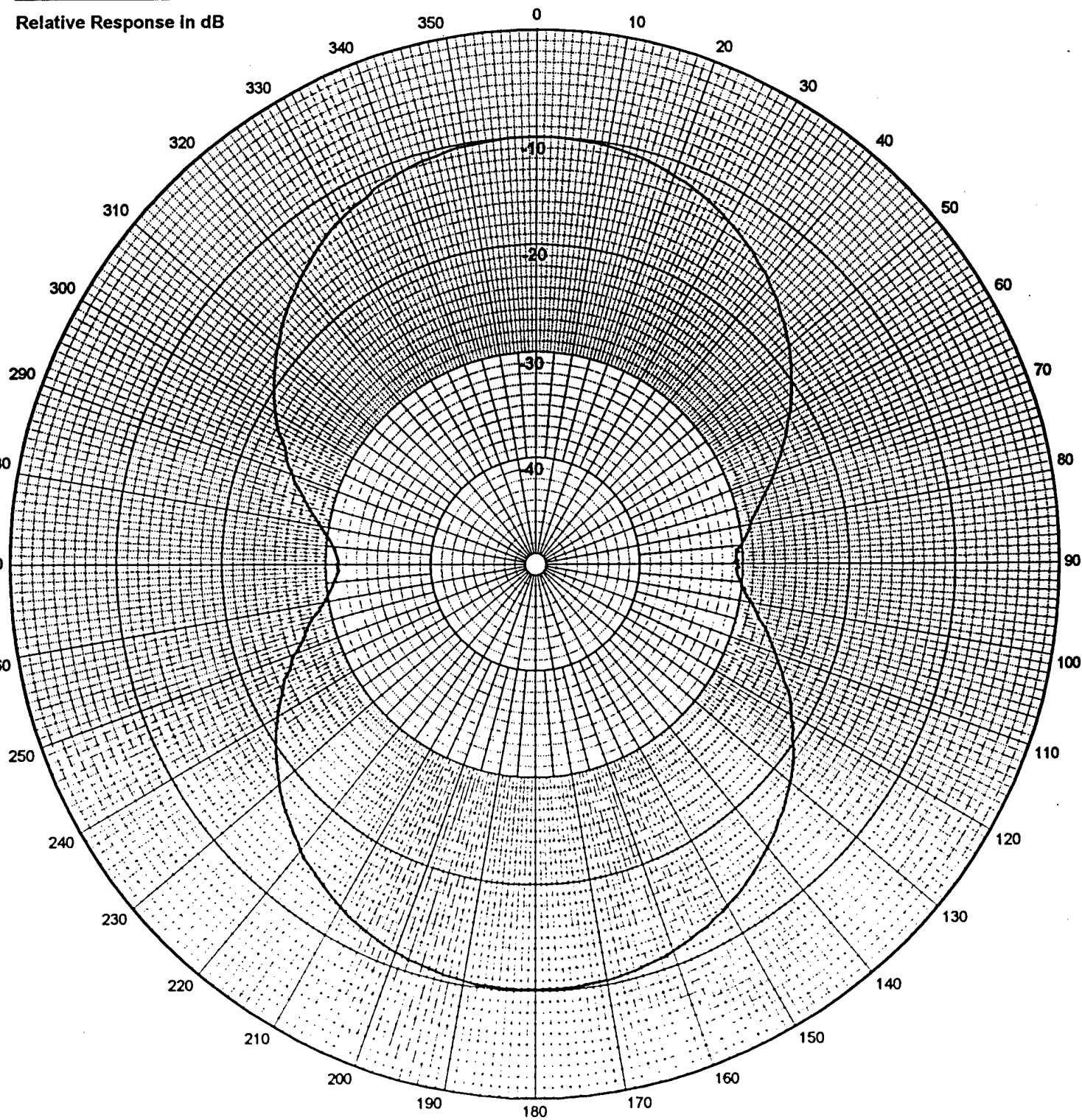
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-29  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB

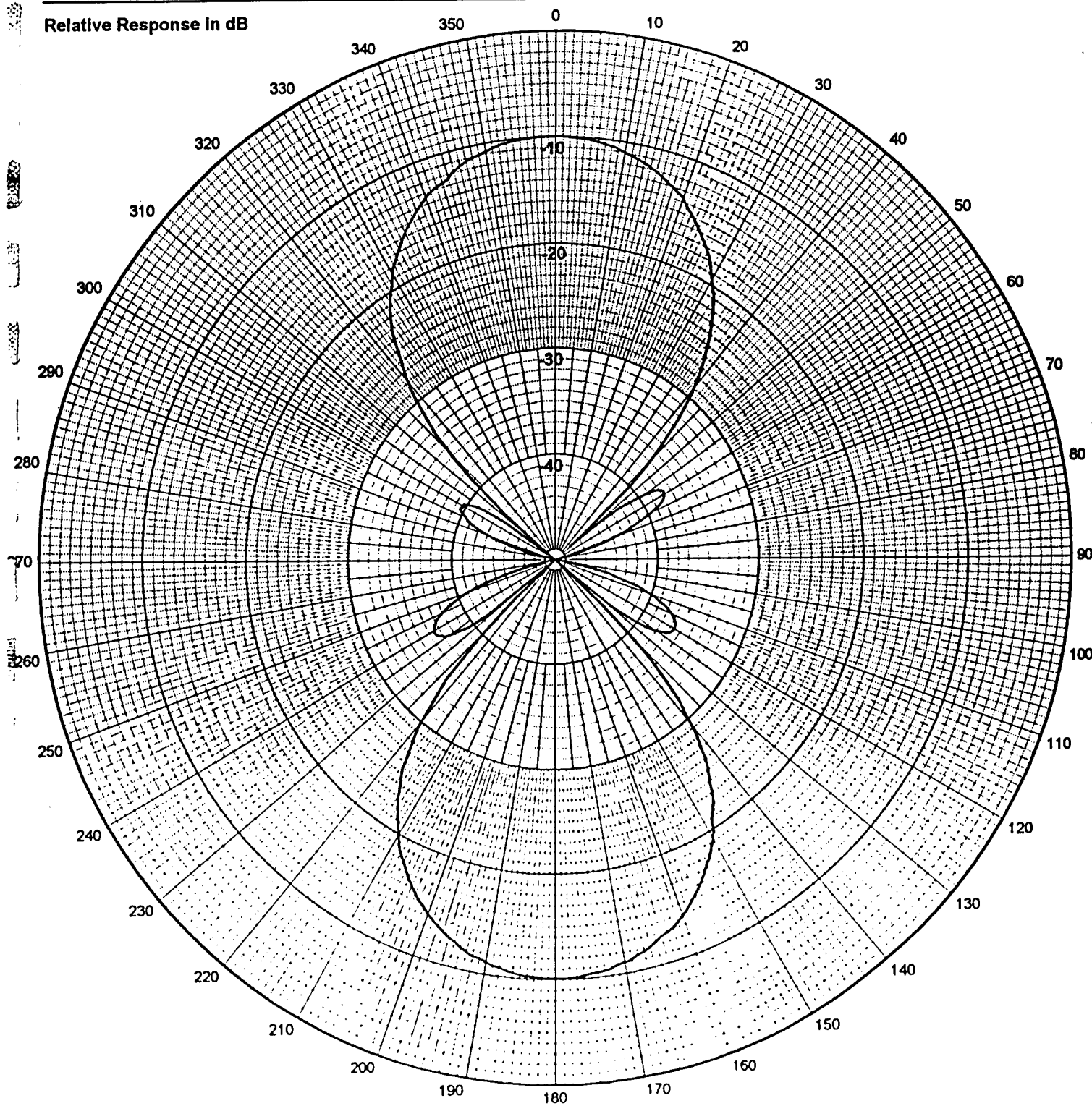


Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



Degrees

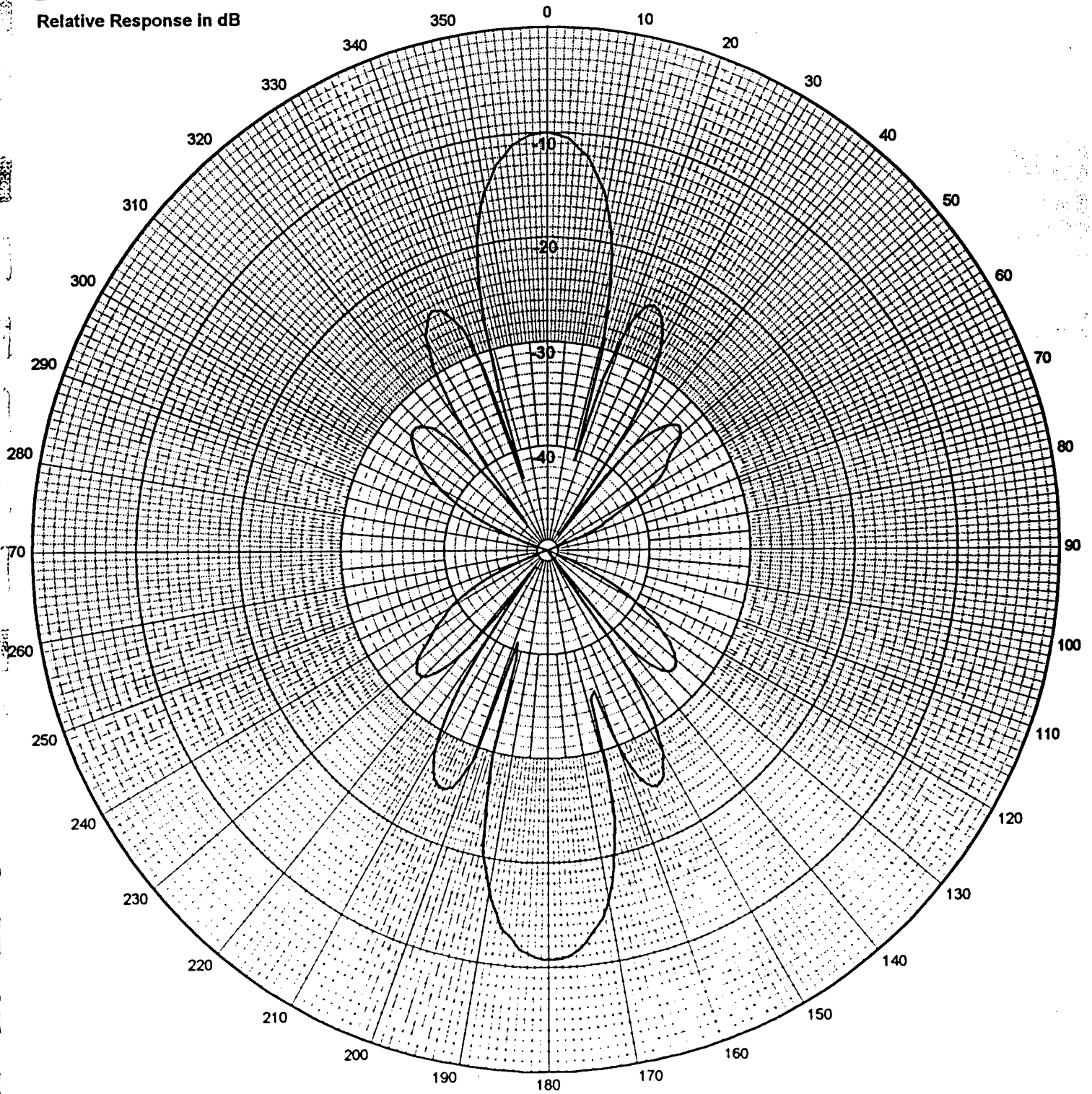
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-31  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB

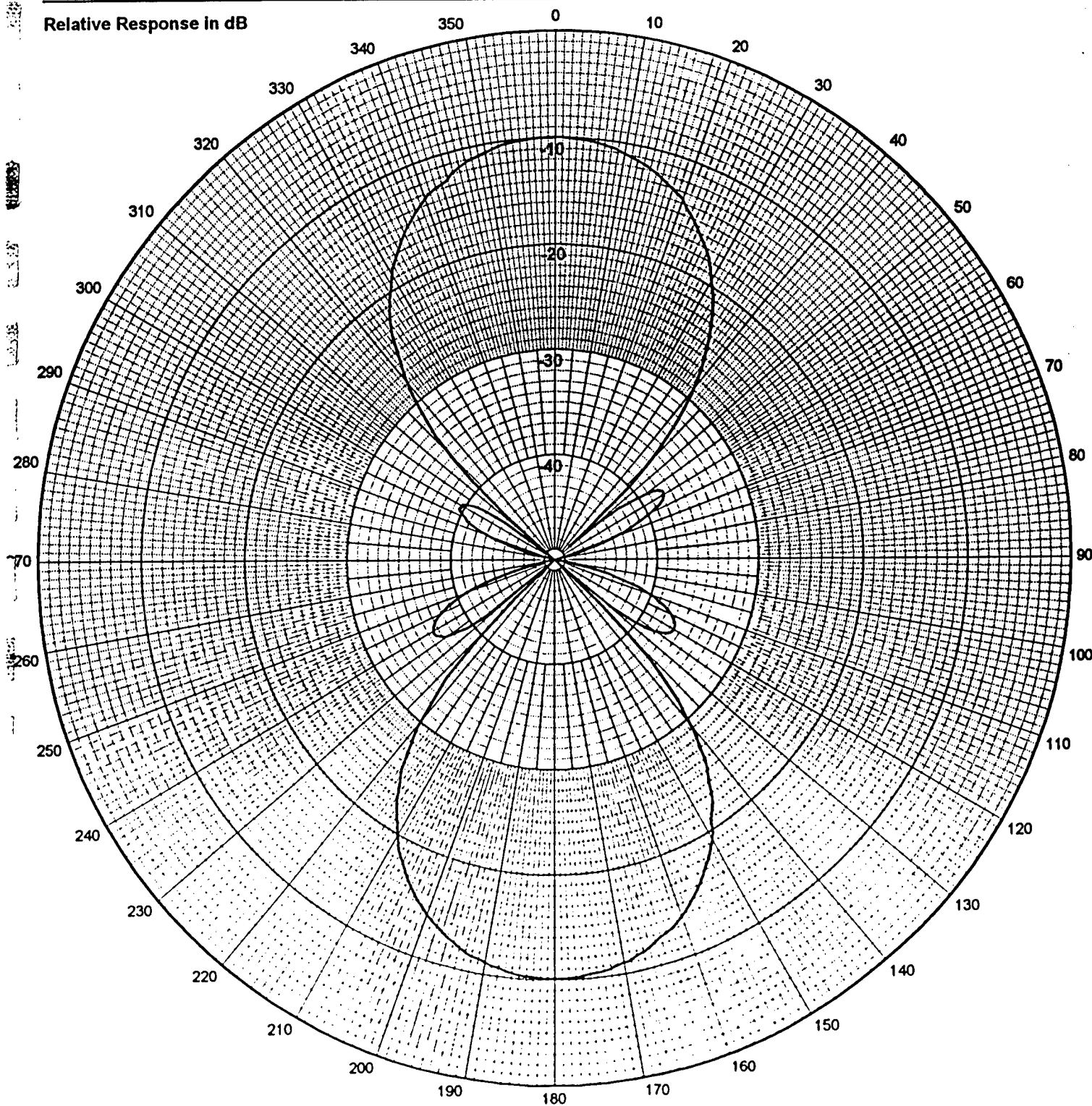


Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



Degrees



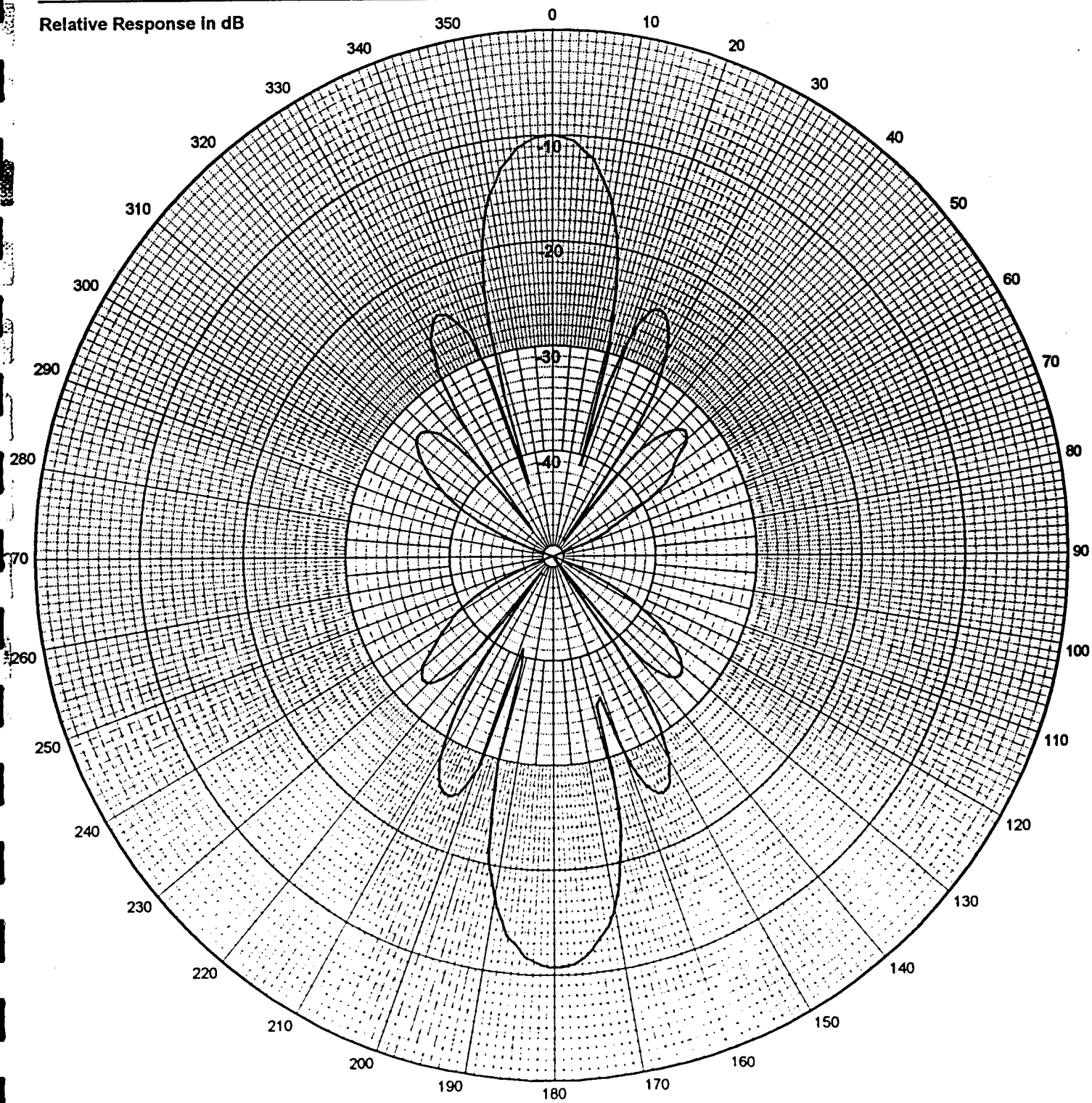
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-31  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB

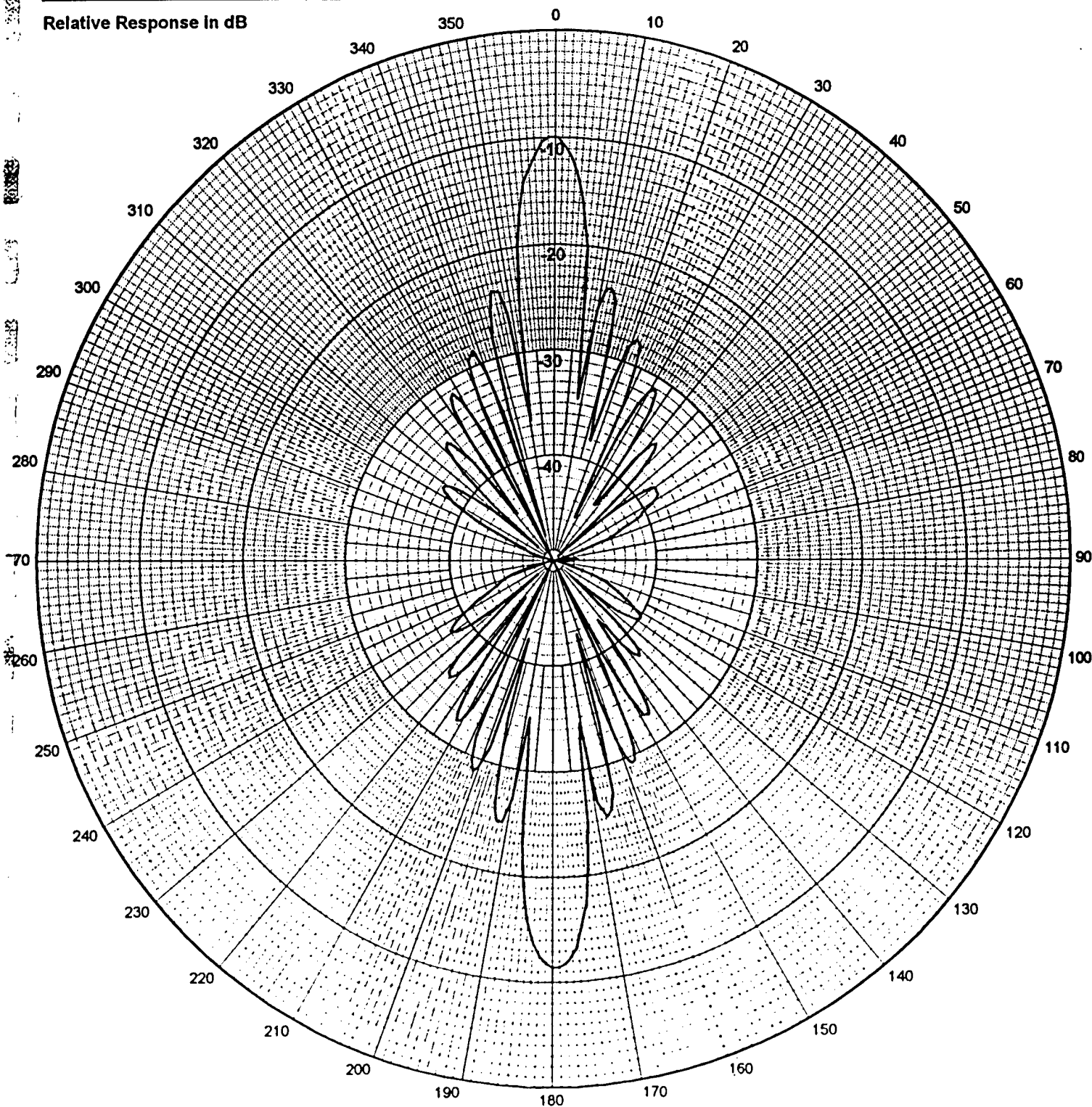


Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



Degrees

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-33  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

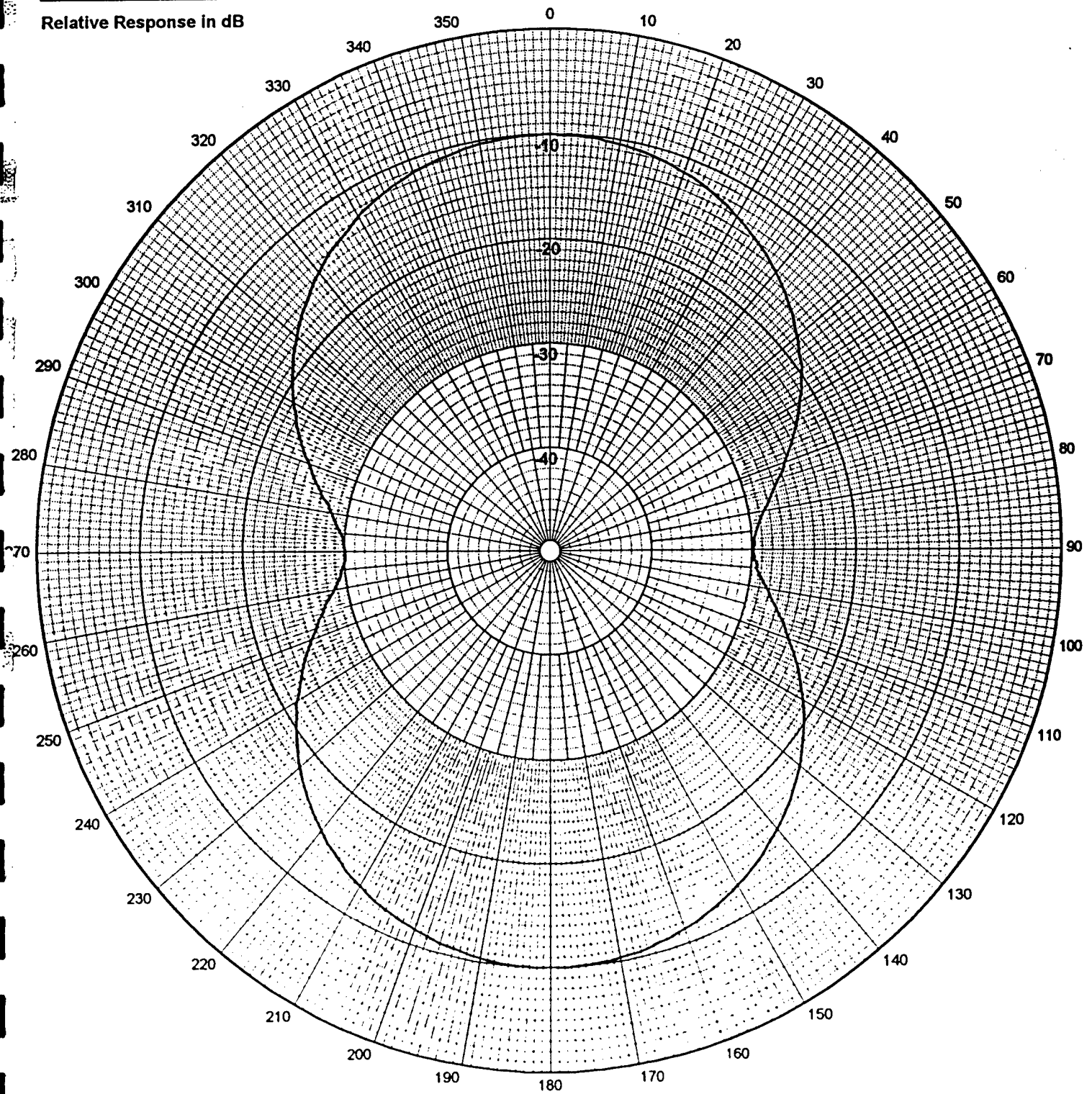
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



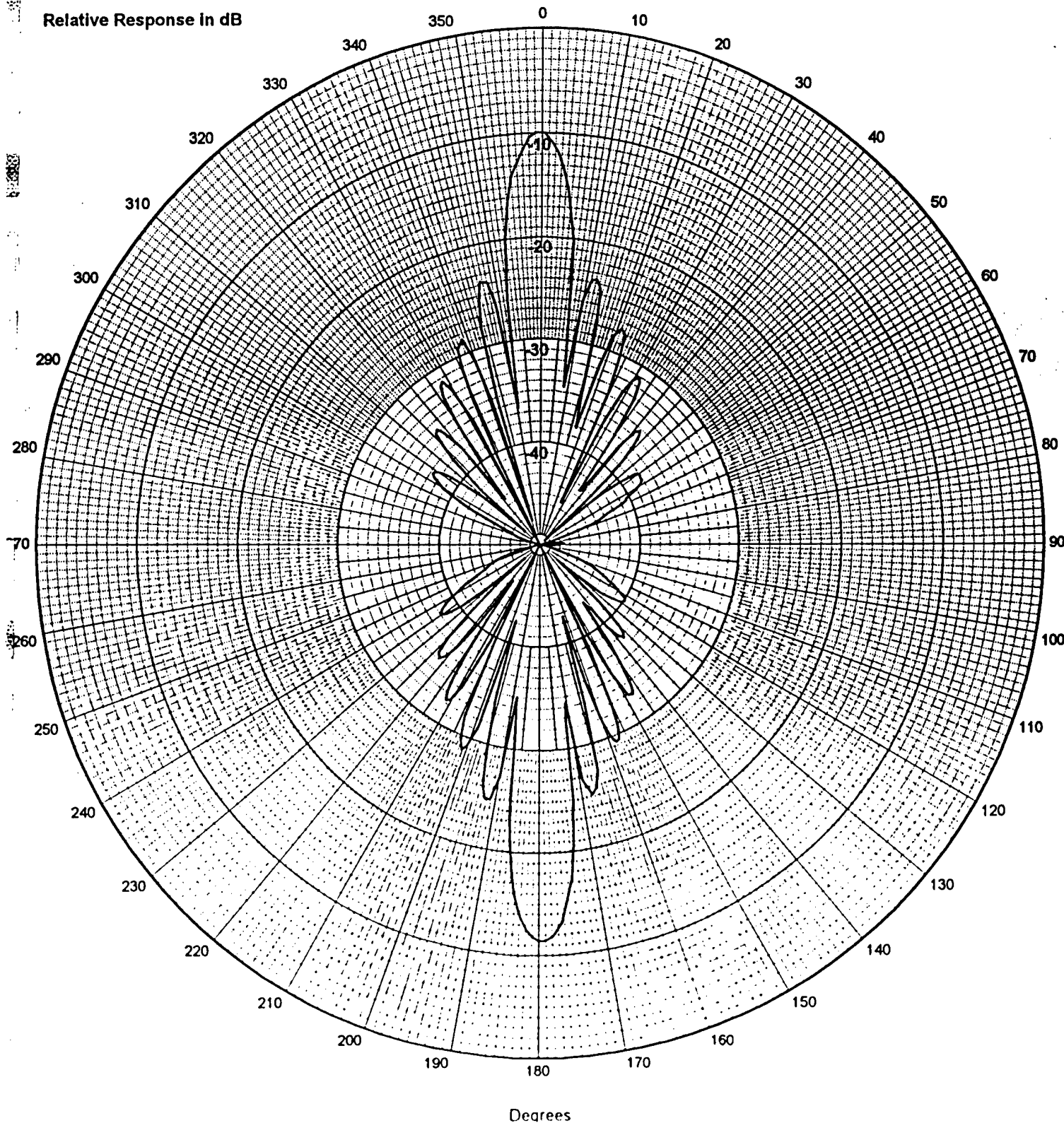
Degrees

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-32  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-33  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

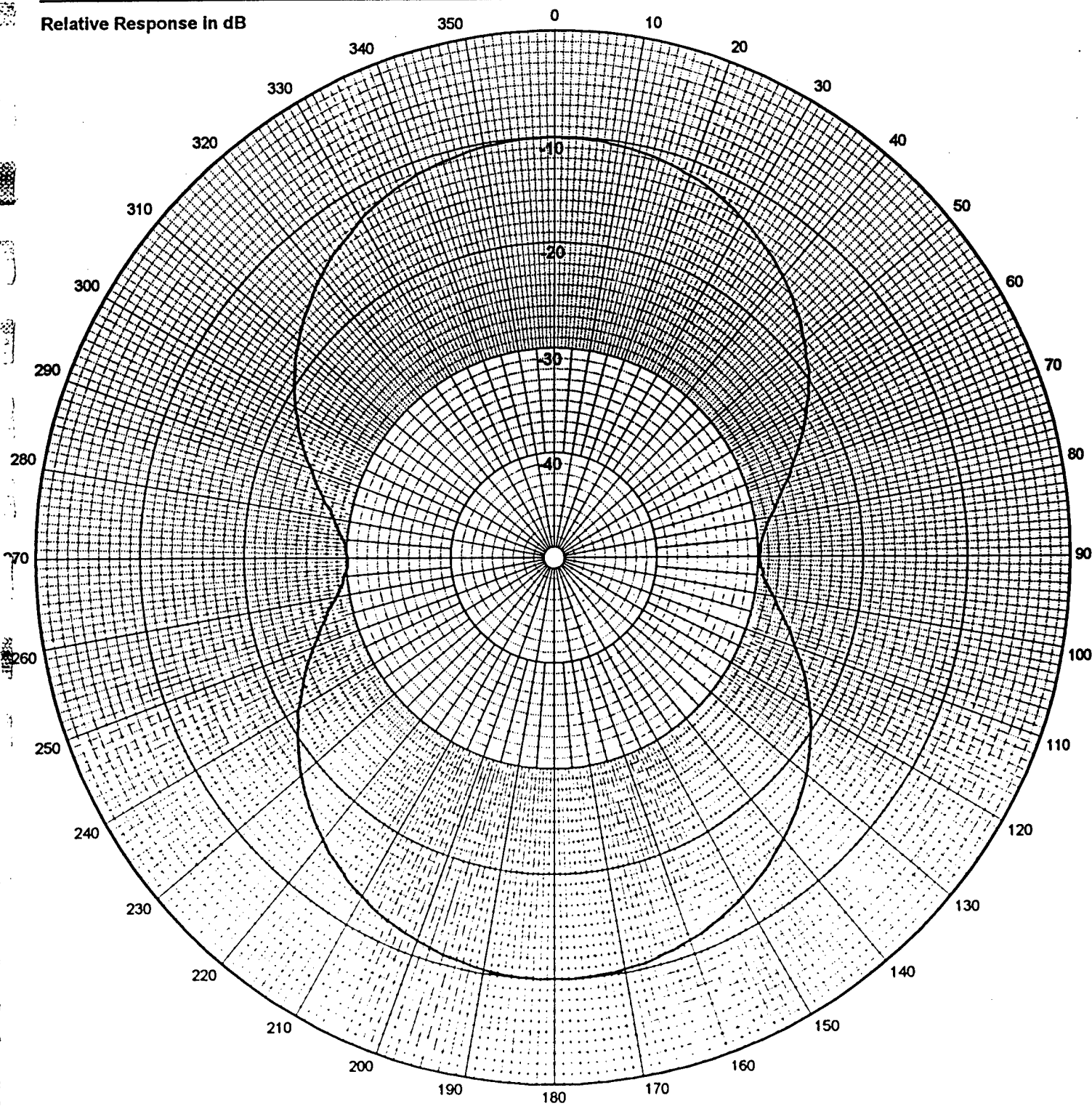
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



Degrees



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

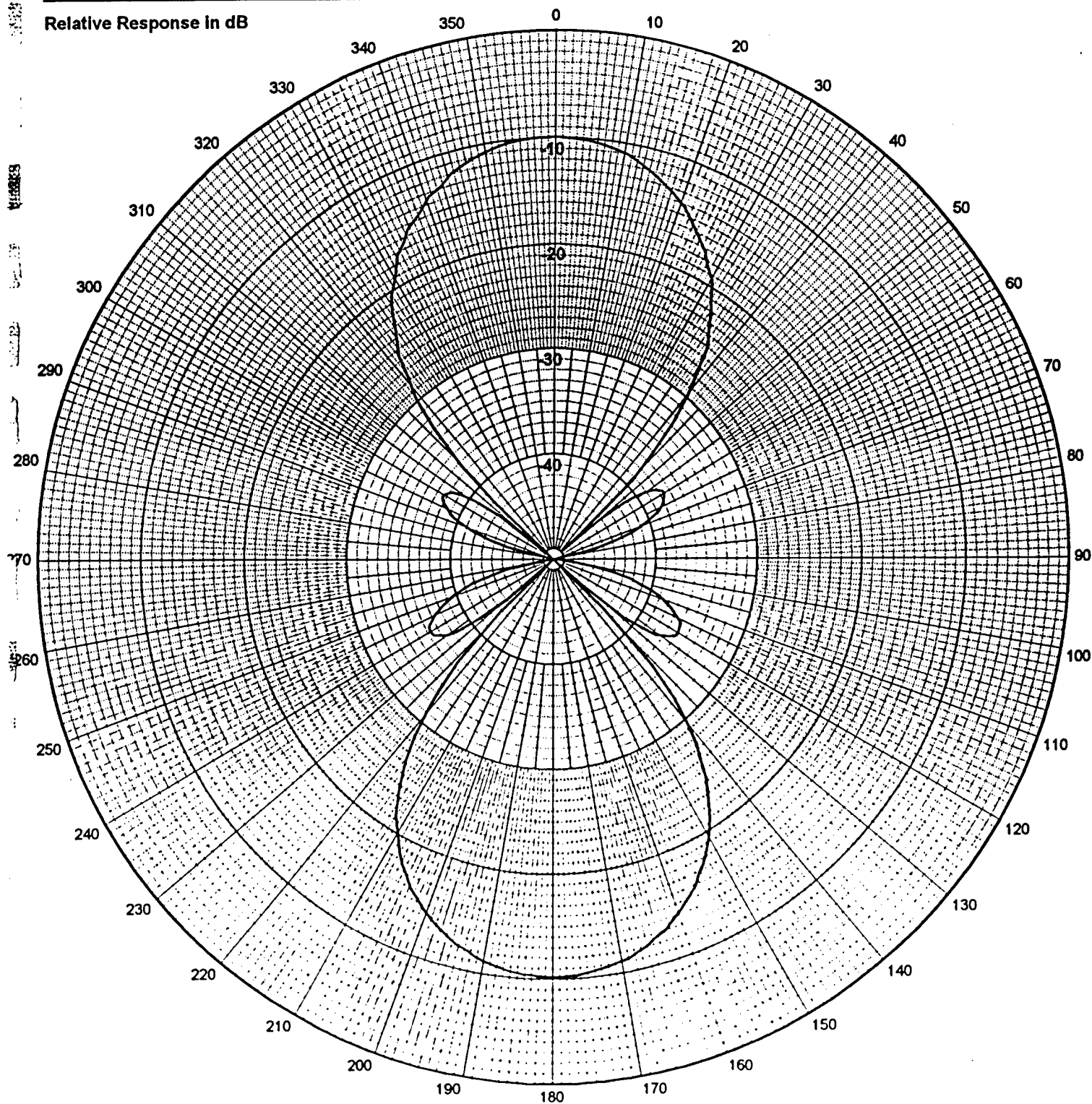
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



Degrees

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-35  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

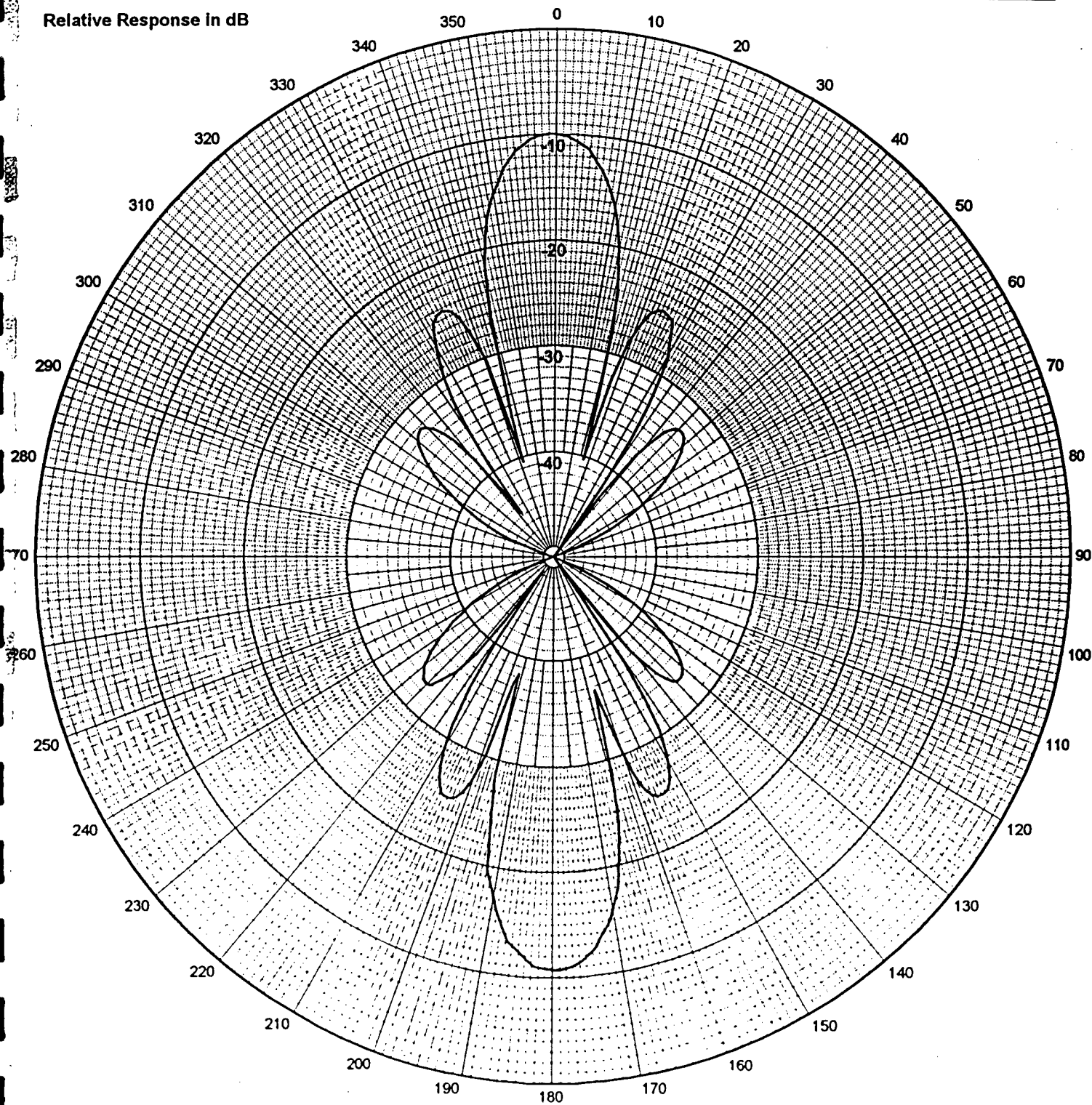
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

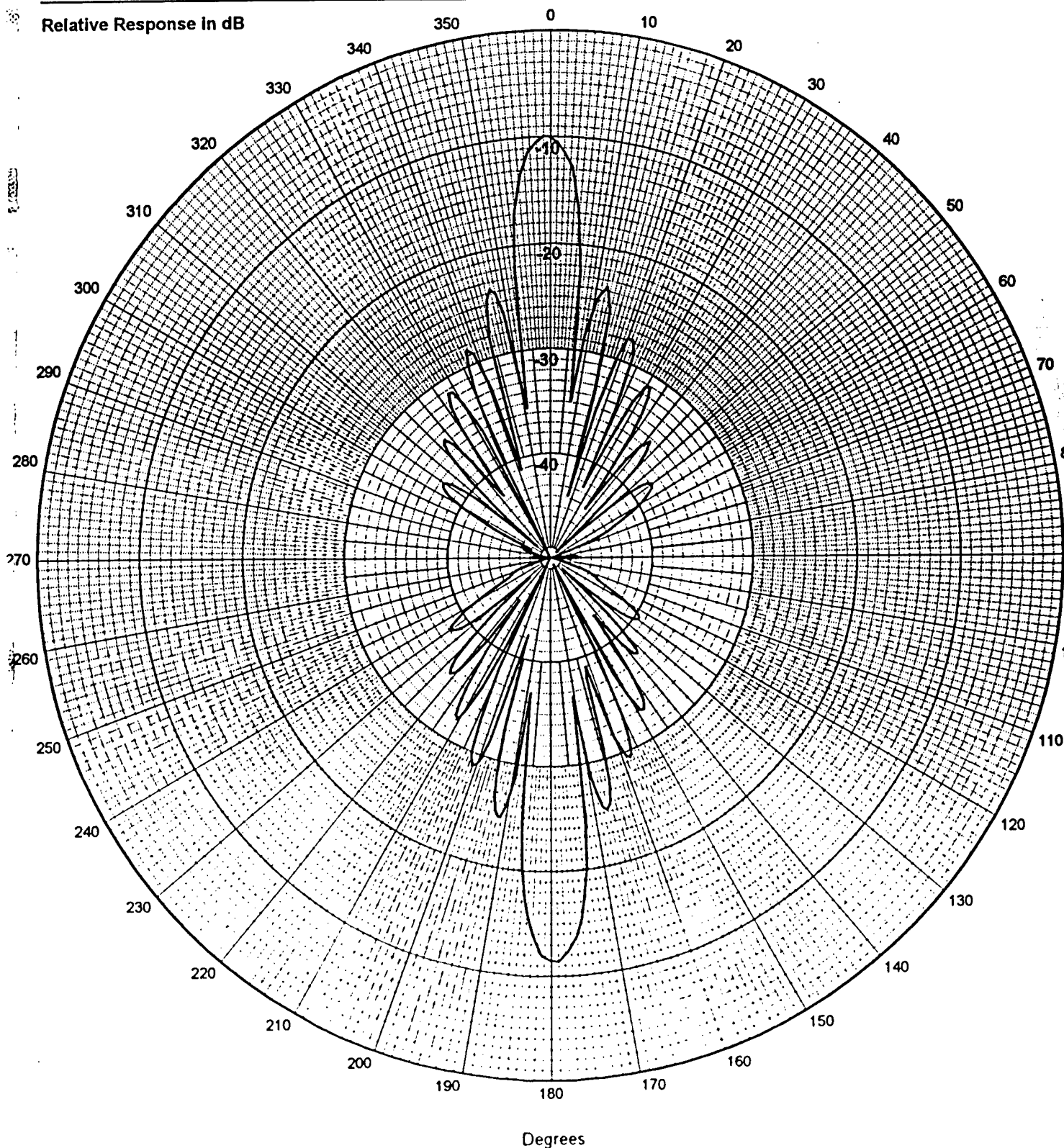
Relative Response in dB



Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz



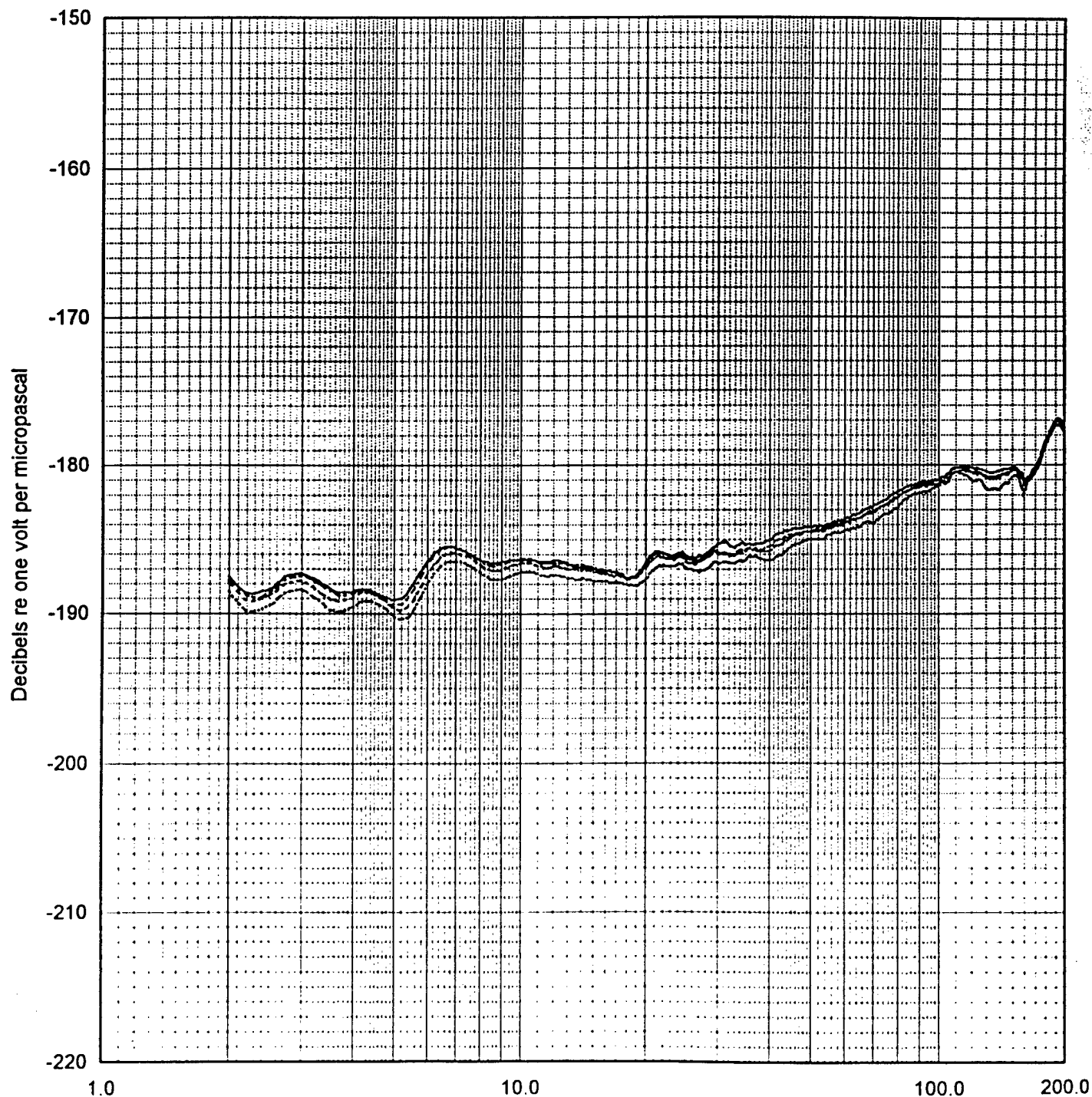
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-50

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

- 16 kPa ( 1.6 m) Before Pressure
- 3448 kPa ( 351.6 m)
- ..... 6895 kPa ( 703.1 m)
- 16 kPa ( 1.6 m) After Pressure



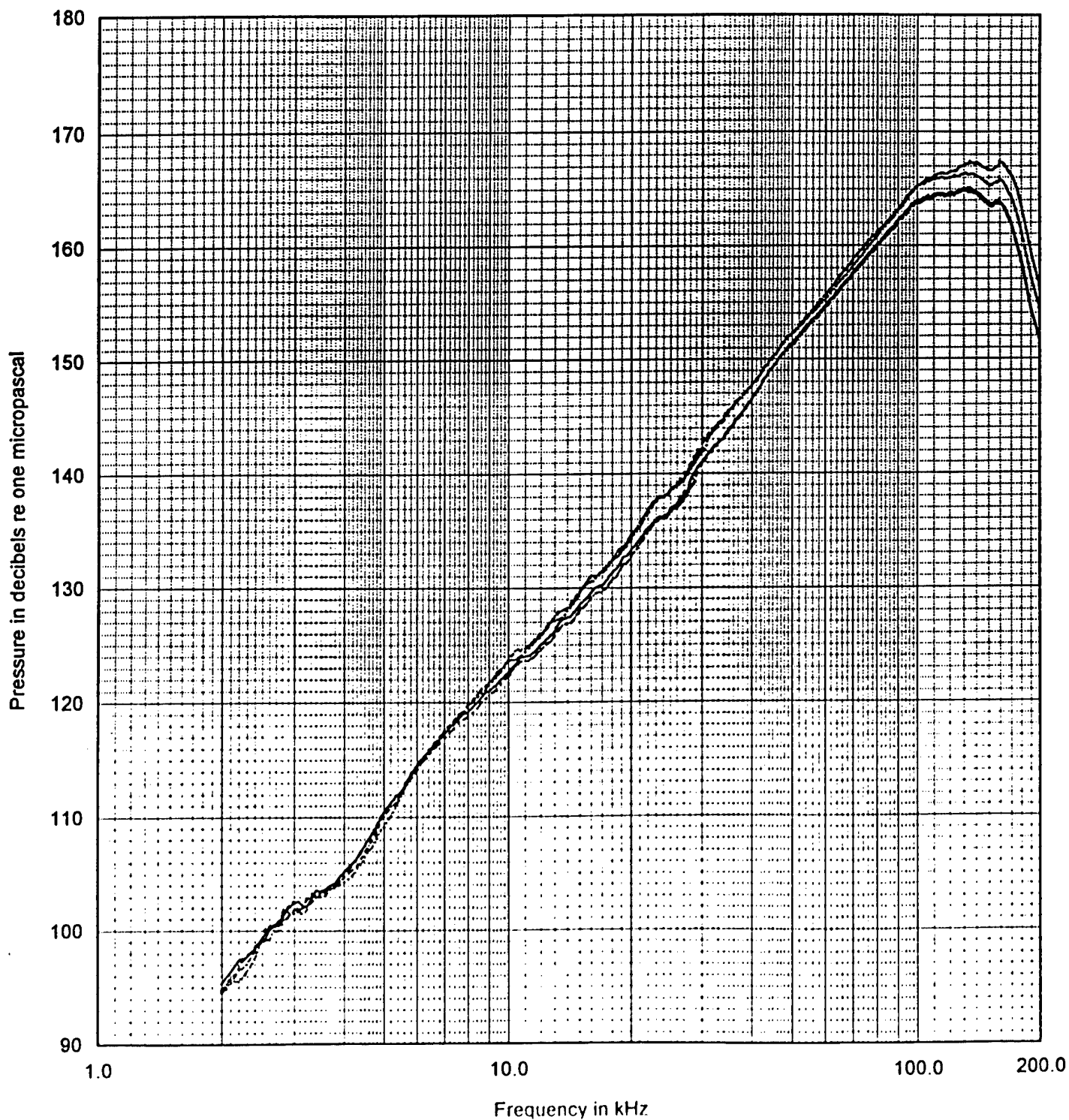
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-50

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
- - - - - 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure





30°  
330°

20°  
340°

10°  
350°

0

USRD NO: 0727-39  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

-10

-20

-30

-40

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
Before Pressure  
XY Plane  
10 kHz

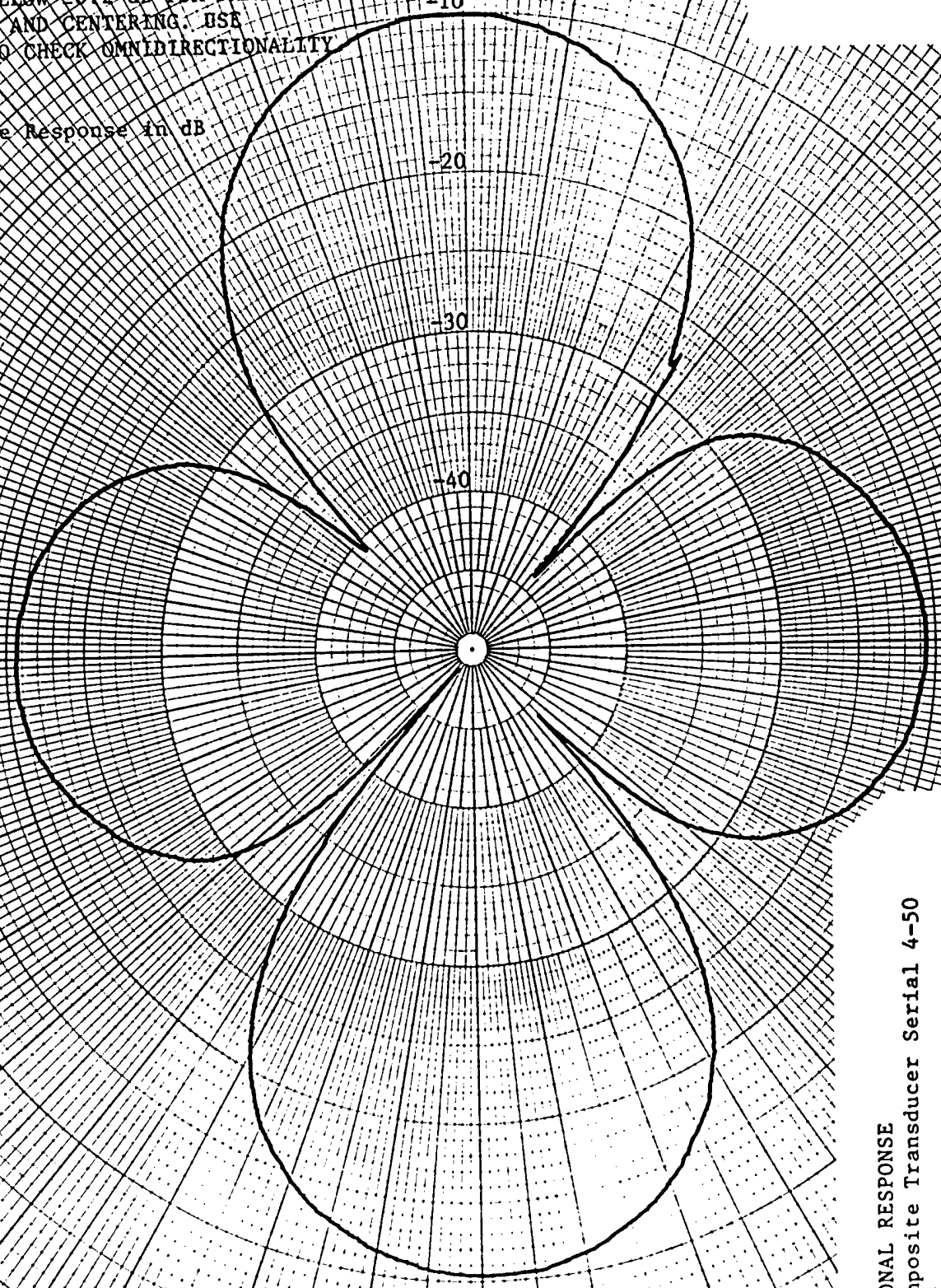
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-40  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
Before Pressure  
XY Plane  
20 kHz

4

30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-41  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

10° 20°  
50° 810°  
60° 800°  
70° 890°  
80° 880°  
90° 870°  
100° 860°  
110° 850°  
120° 840°  
130° 830°  
140° 820°

320° 40°  
310° 50°  
300° 60°  
290° 70°  
280° 80°  
270° 90°  
260° 100°  
250° 110°  
240° 120°  
230° 130°  
220° 140°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
Before Pressure  
XY Plane  
50 kHz

330°  
30°

NOTE: ALLOW 20.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
Before Pressure  
XY plane  
100 kHz

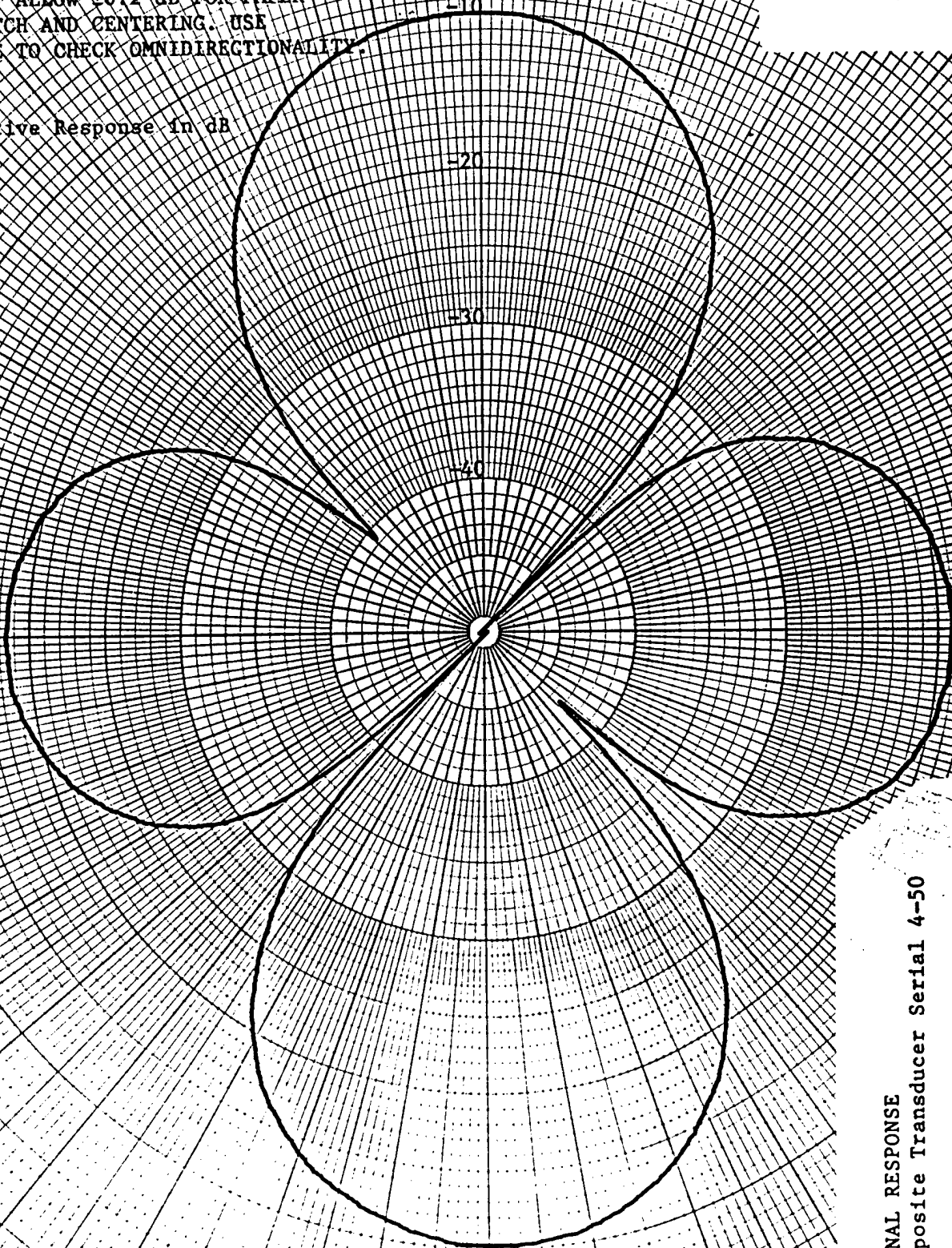


30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-44  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
XY Plane  
20 kHz



30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO:

0727-45

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDREX PRESS:

3448 kPa (351.6 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING, USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

30°  
810°30°  
00°70°  
290°80°  
80°90°  
70°00°  
60°10°  
250°120°  
140°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

45  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

USRD NO:

0727-46

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

3448 kPa (351.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

46  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
XY Plane  
100 kHz

30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO: 0727-47  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 (703.1 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

47  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
XY Plane  
10 kHz

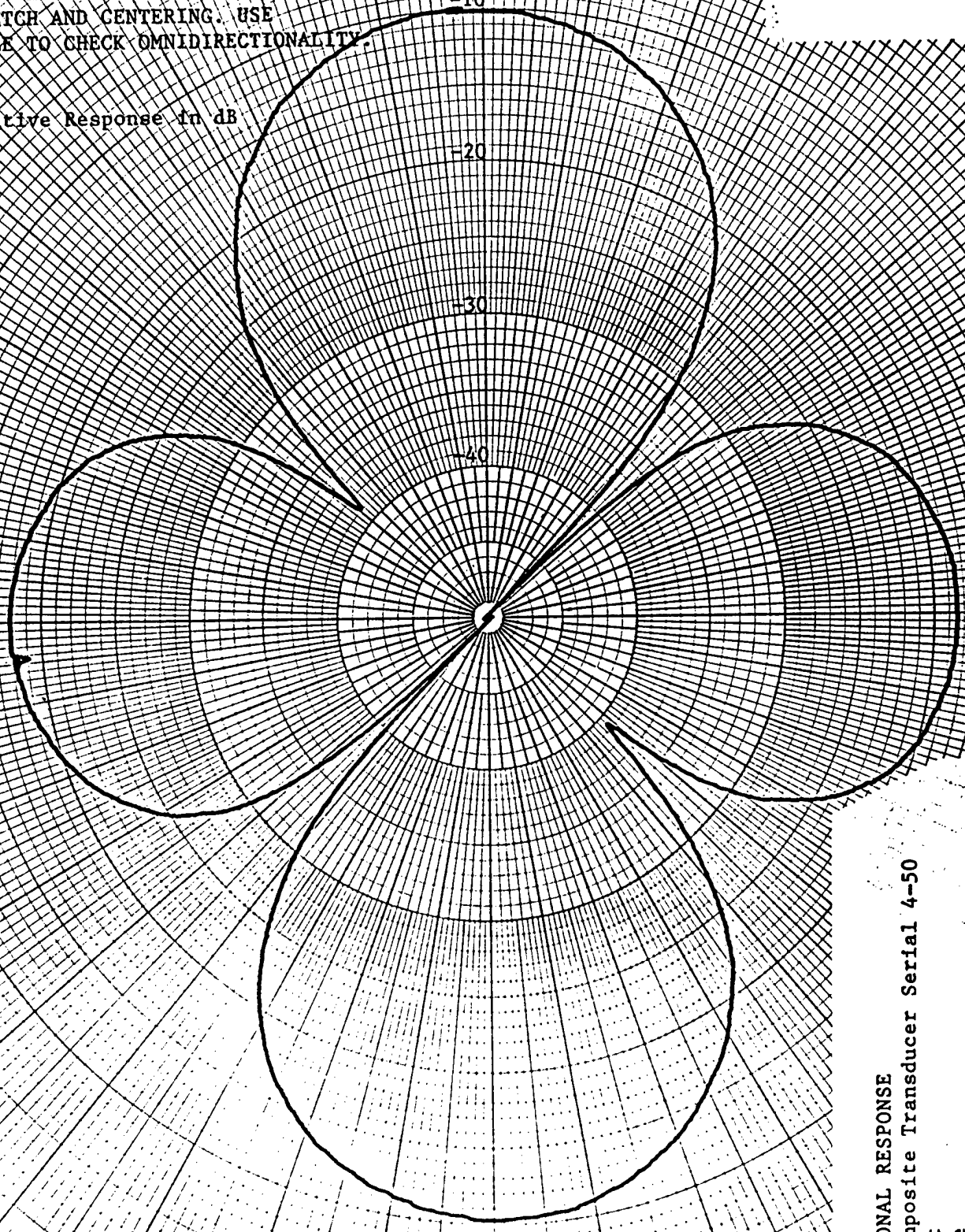
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-48  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

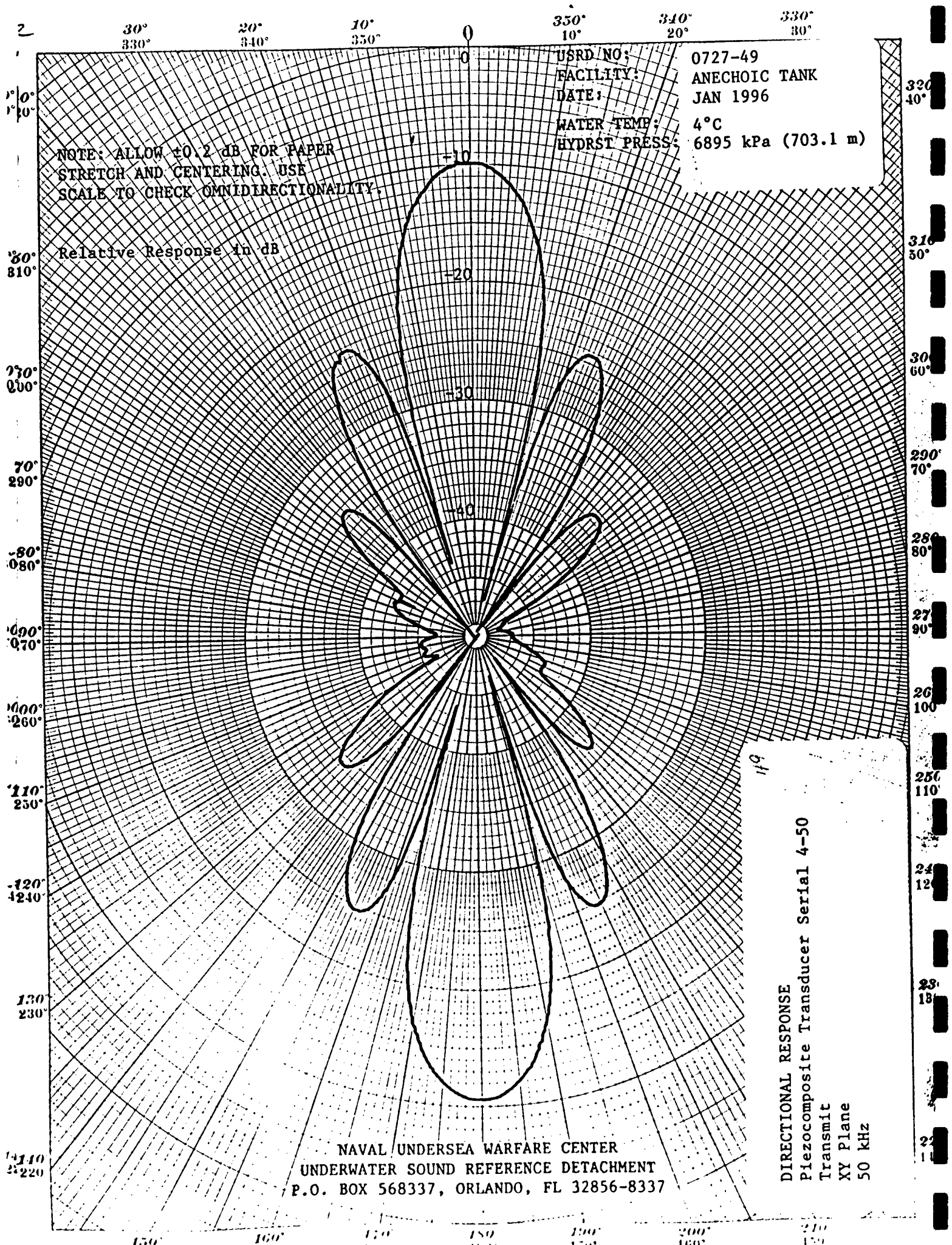


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UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
XY Plane  
20 kHz

150° 160° 170° 180° 190° 200° 210°  
150 160 170 180 190 200 210





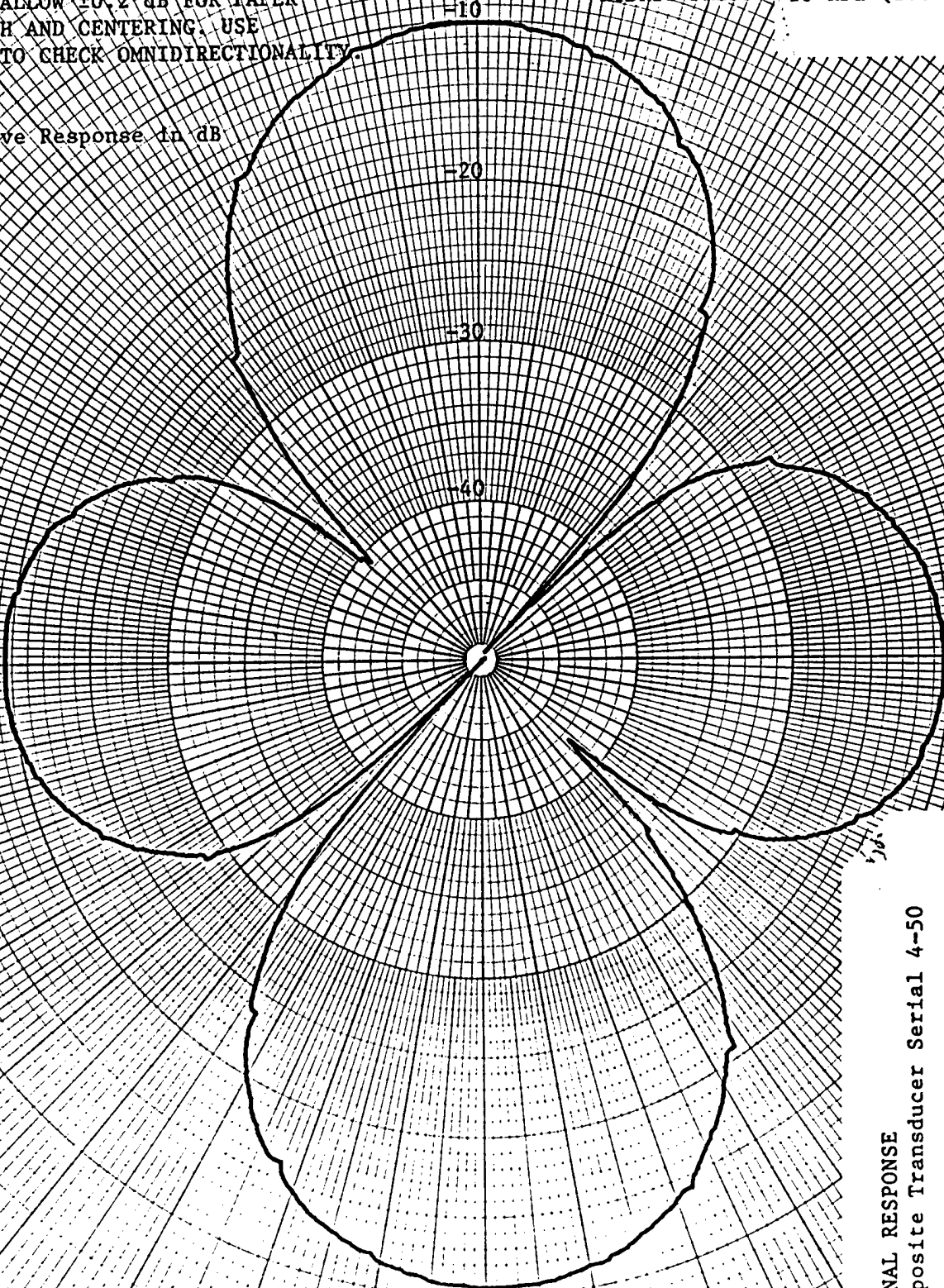


30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-52  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
After Pressure  
XY Plane  
20 kHz

30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO:

0727-53

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

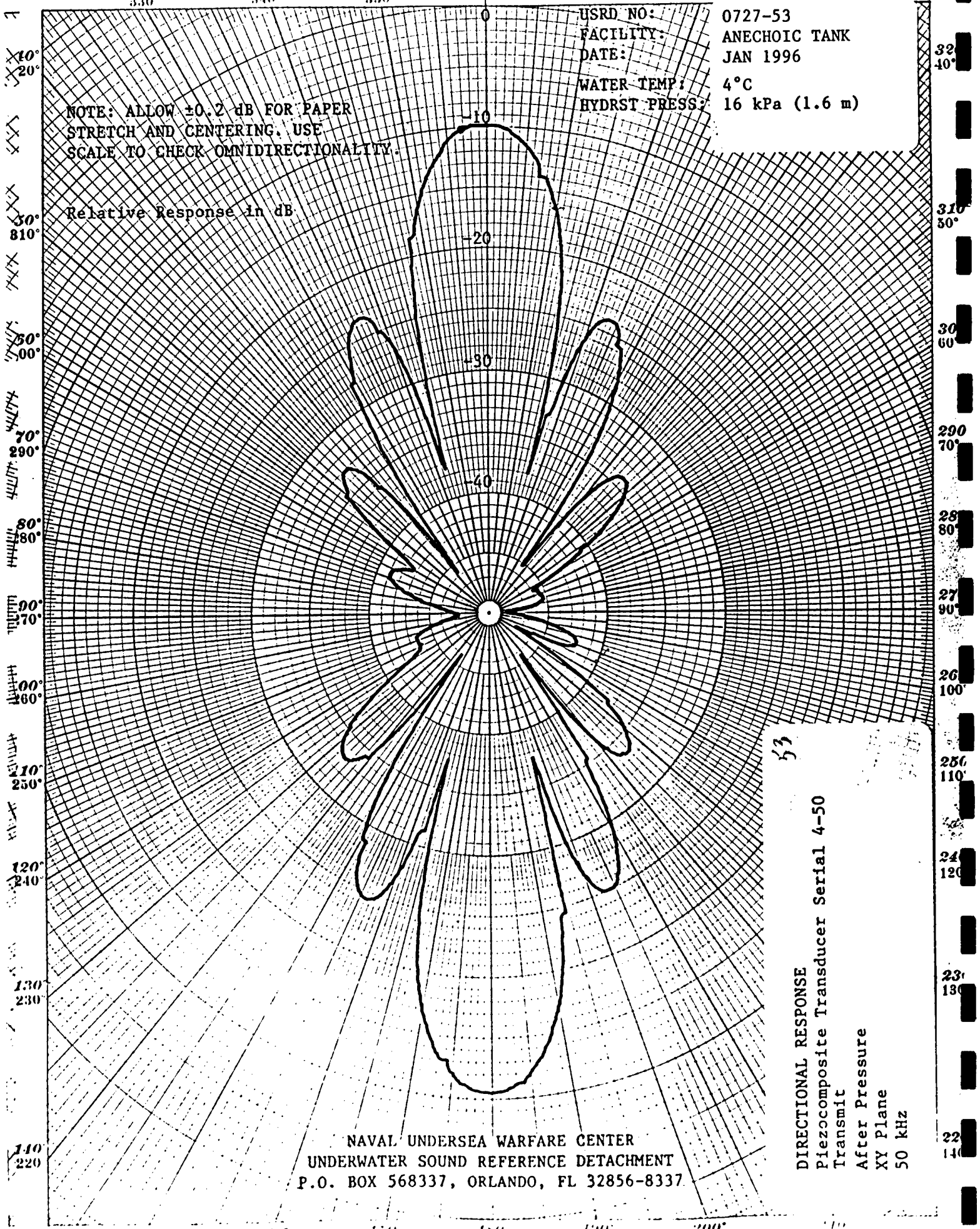
4°C

HYDRST PRESS:

16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

53  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-50  
Transmit  
After Pressure  
XY Plane  
50 kHz

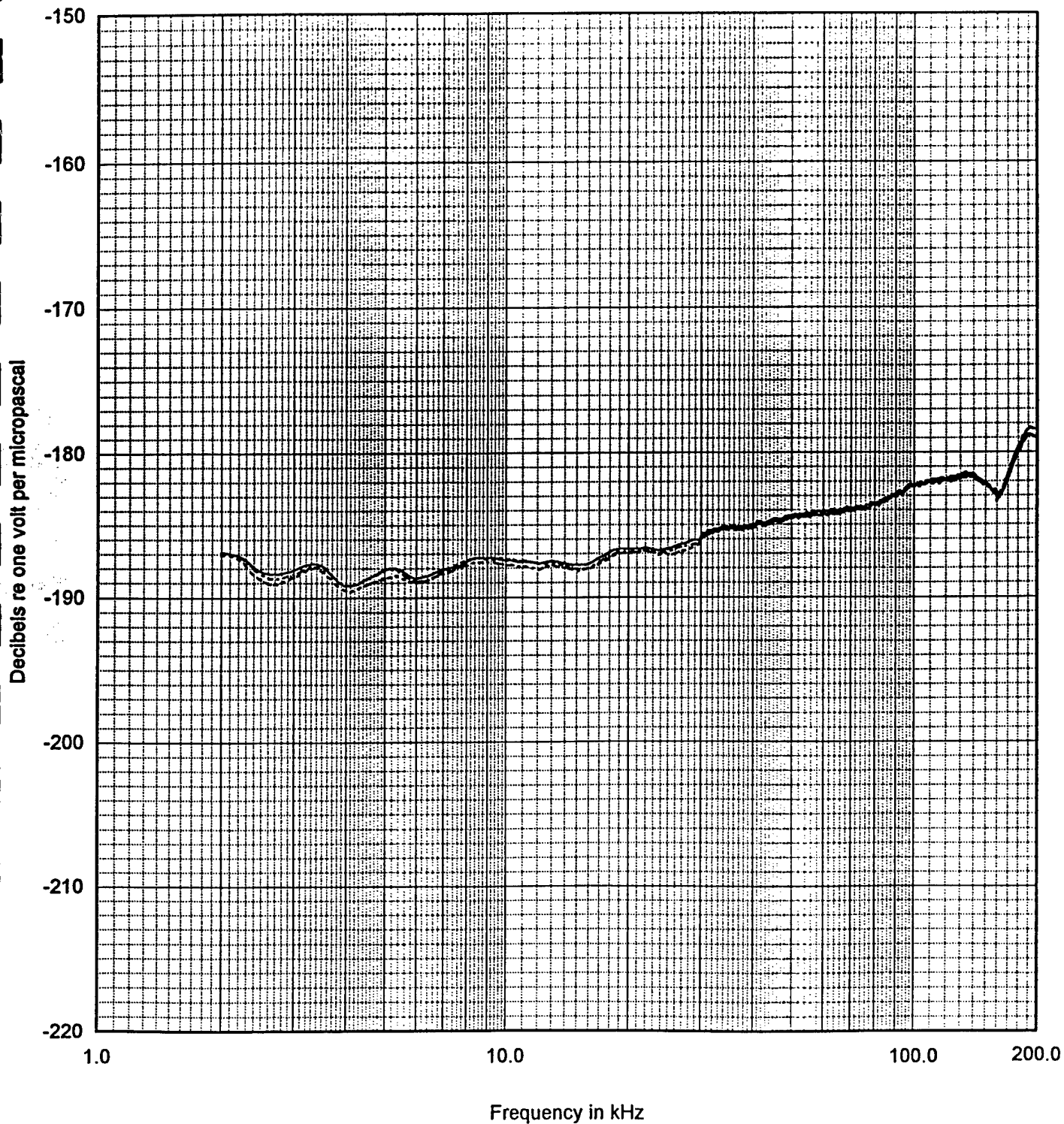
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-50

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
- - - 16 kPa ( 1.6 m) After Pressure



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

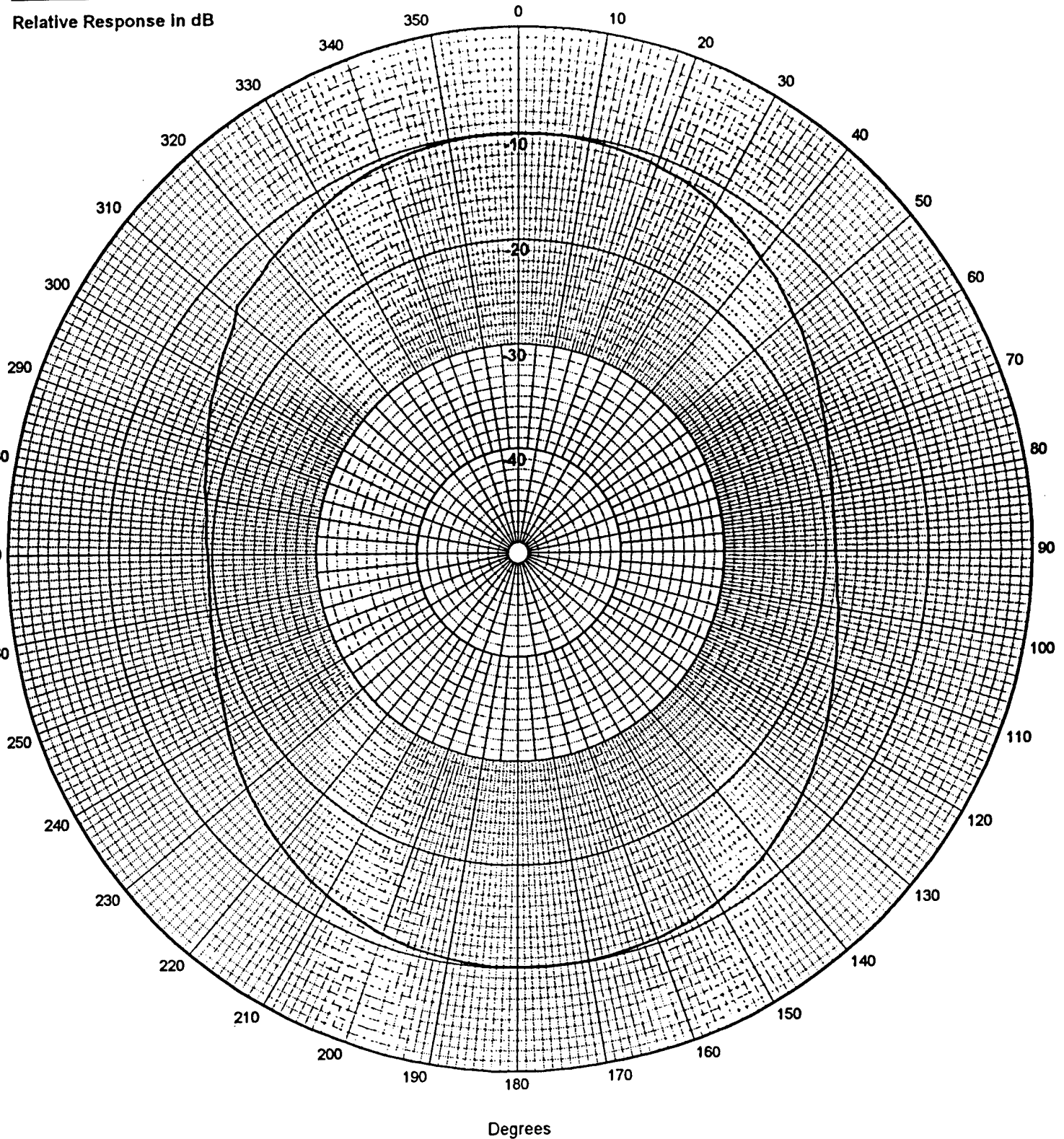
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB





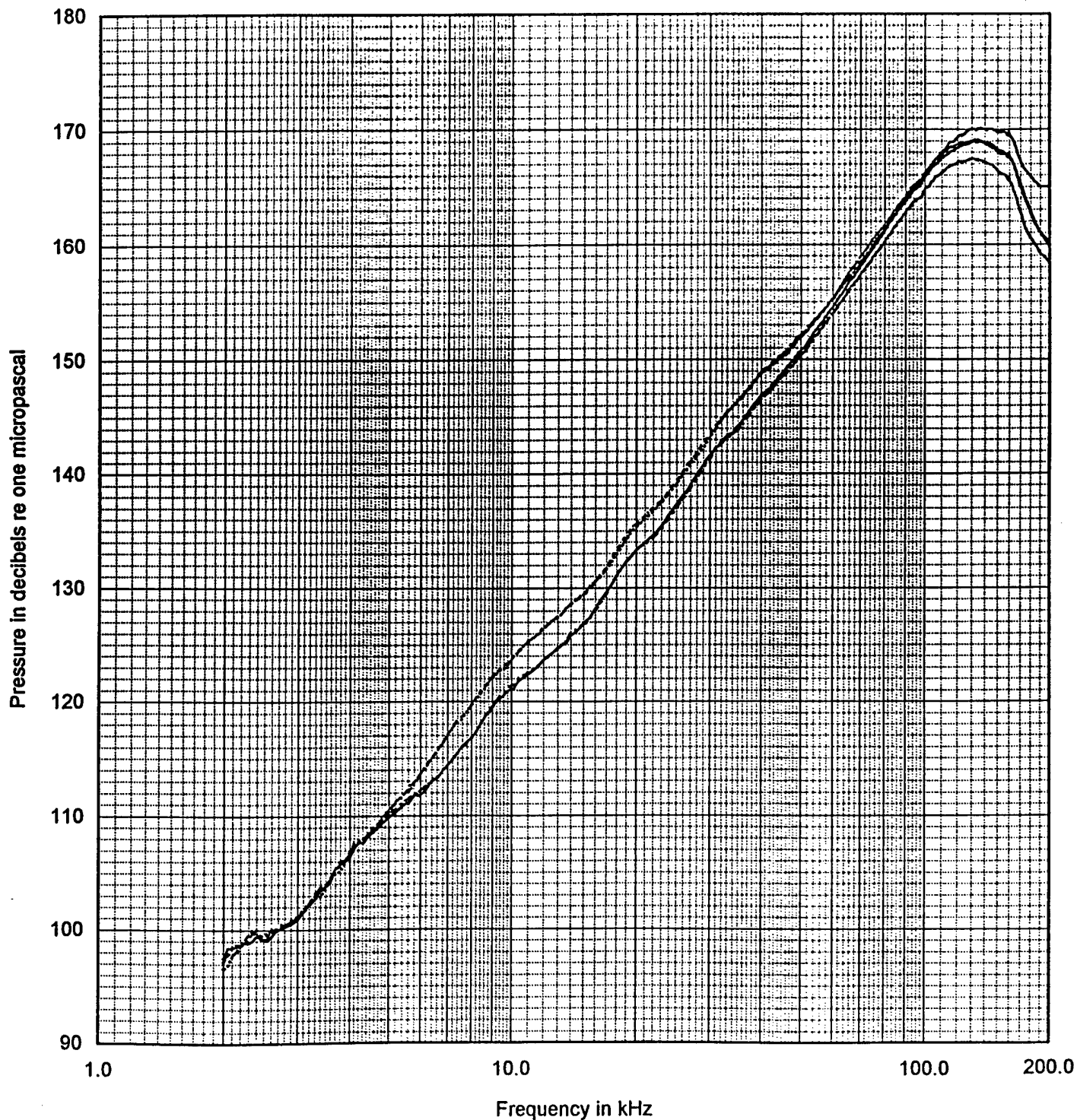
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-50

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

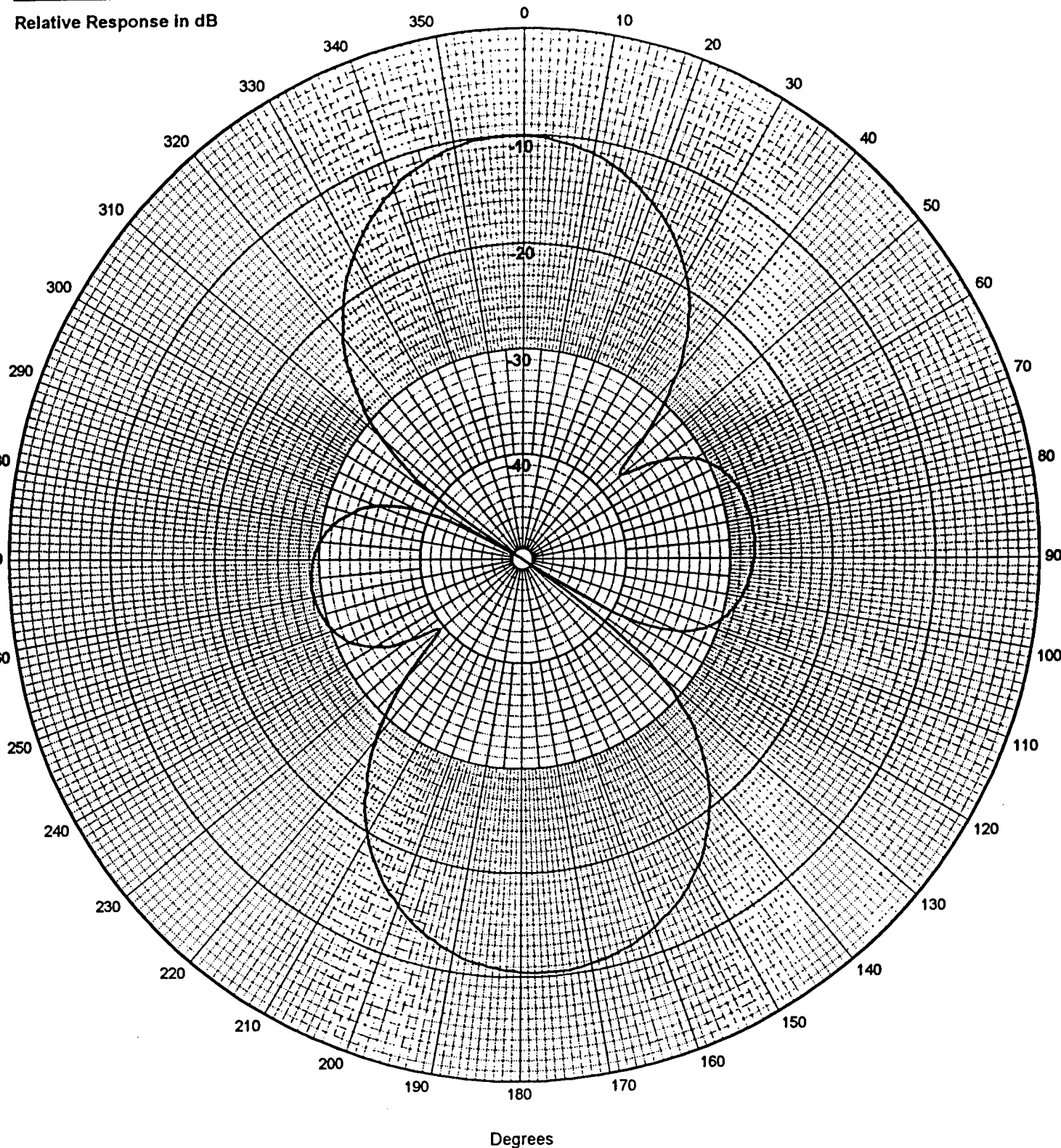
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

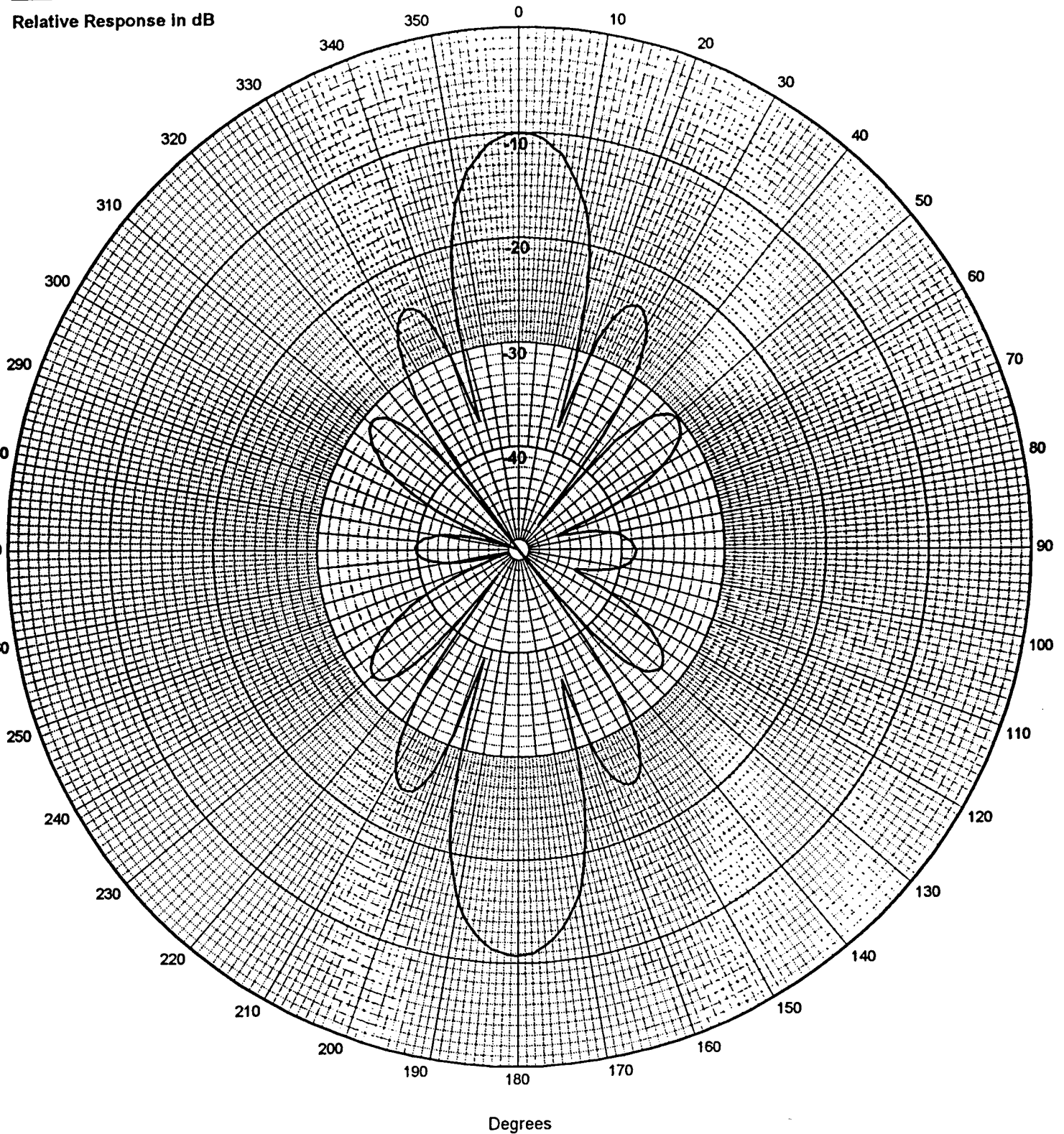
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

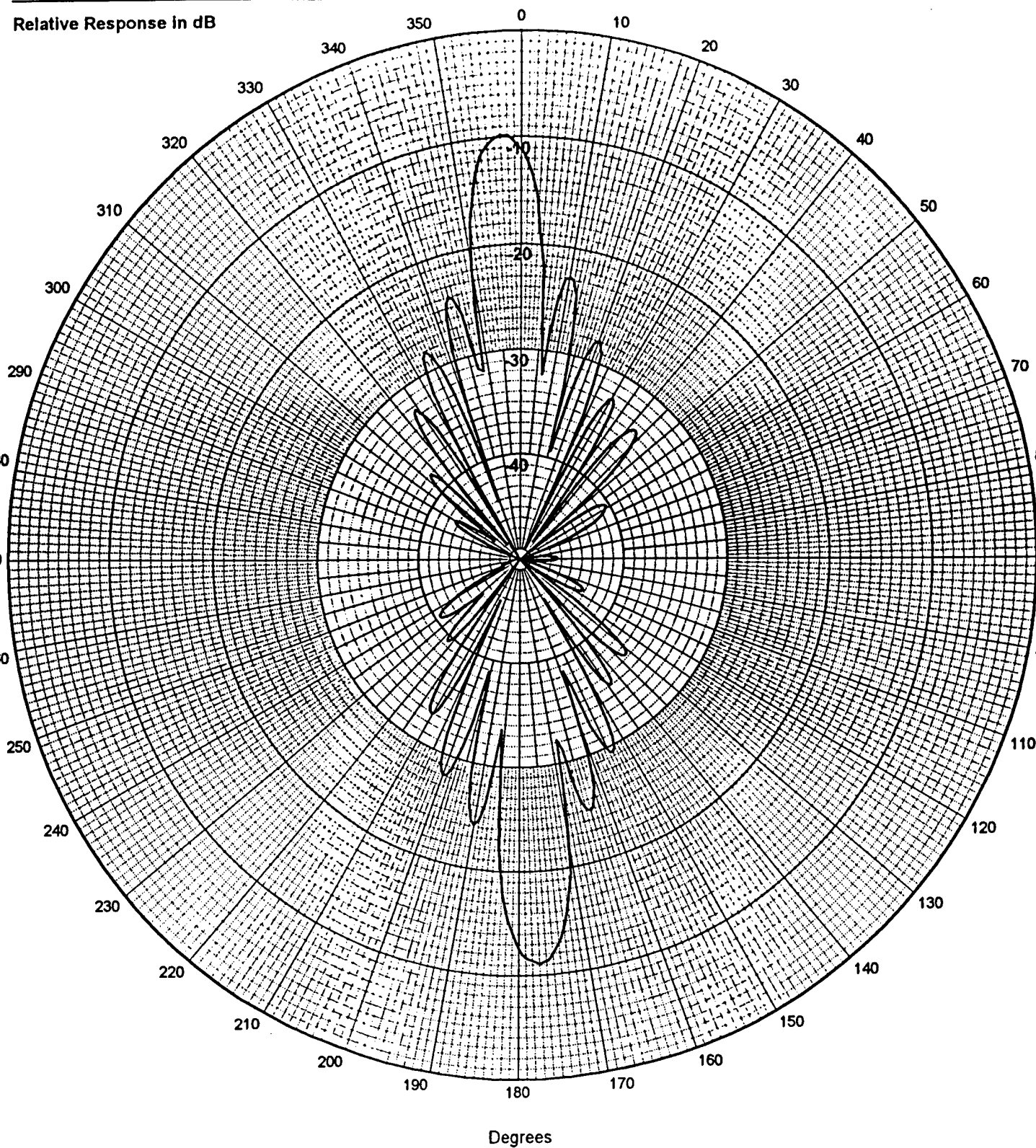
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

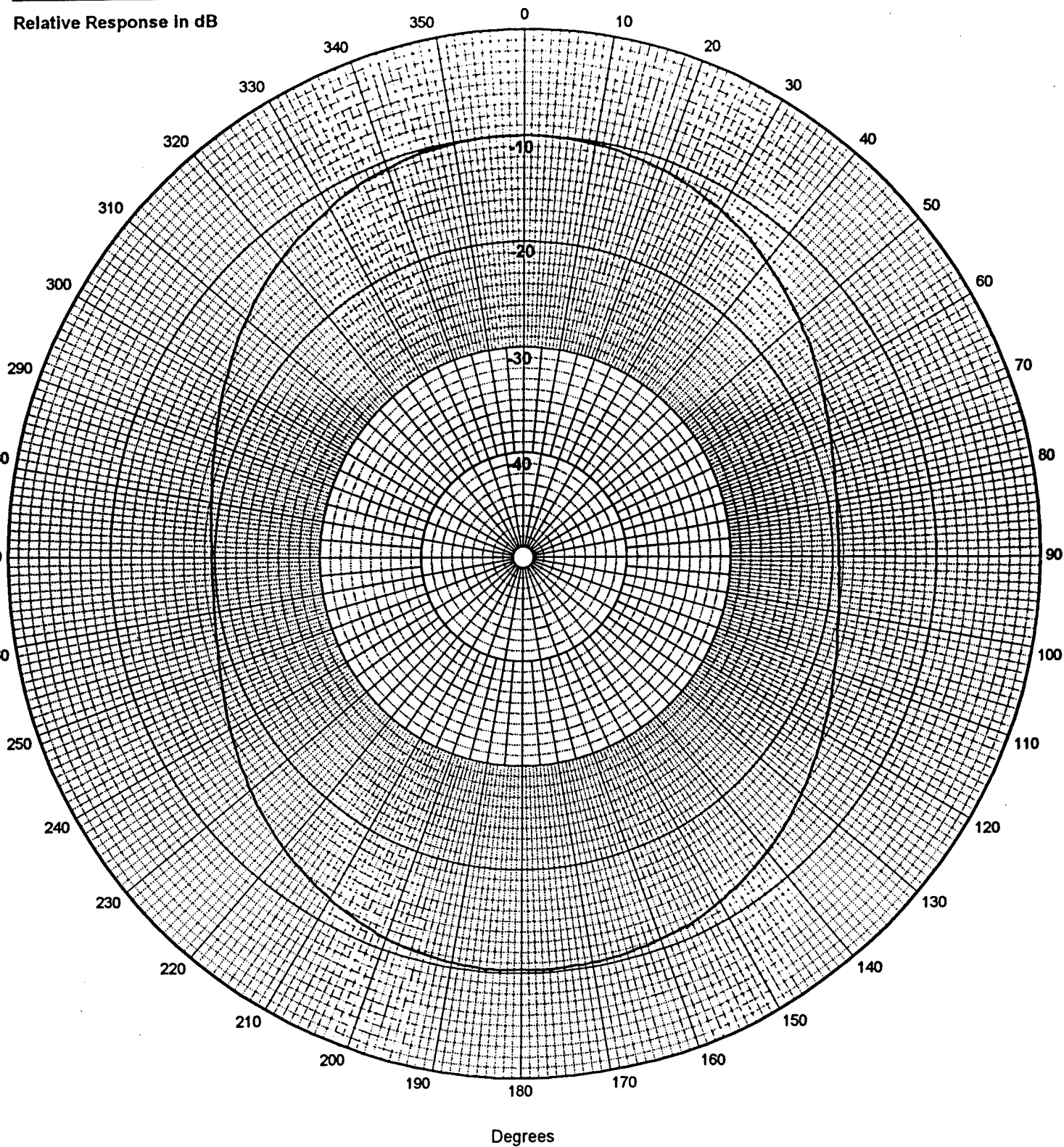
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB

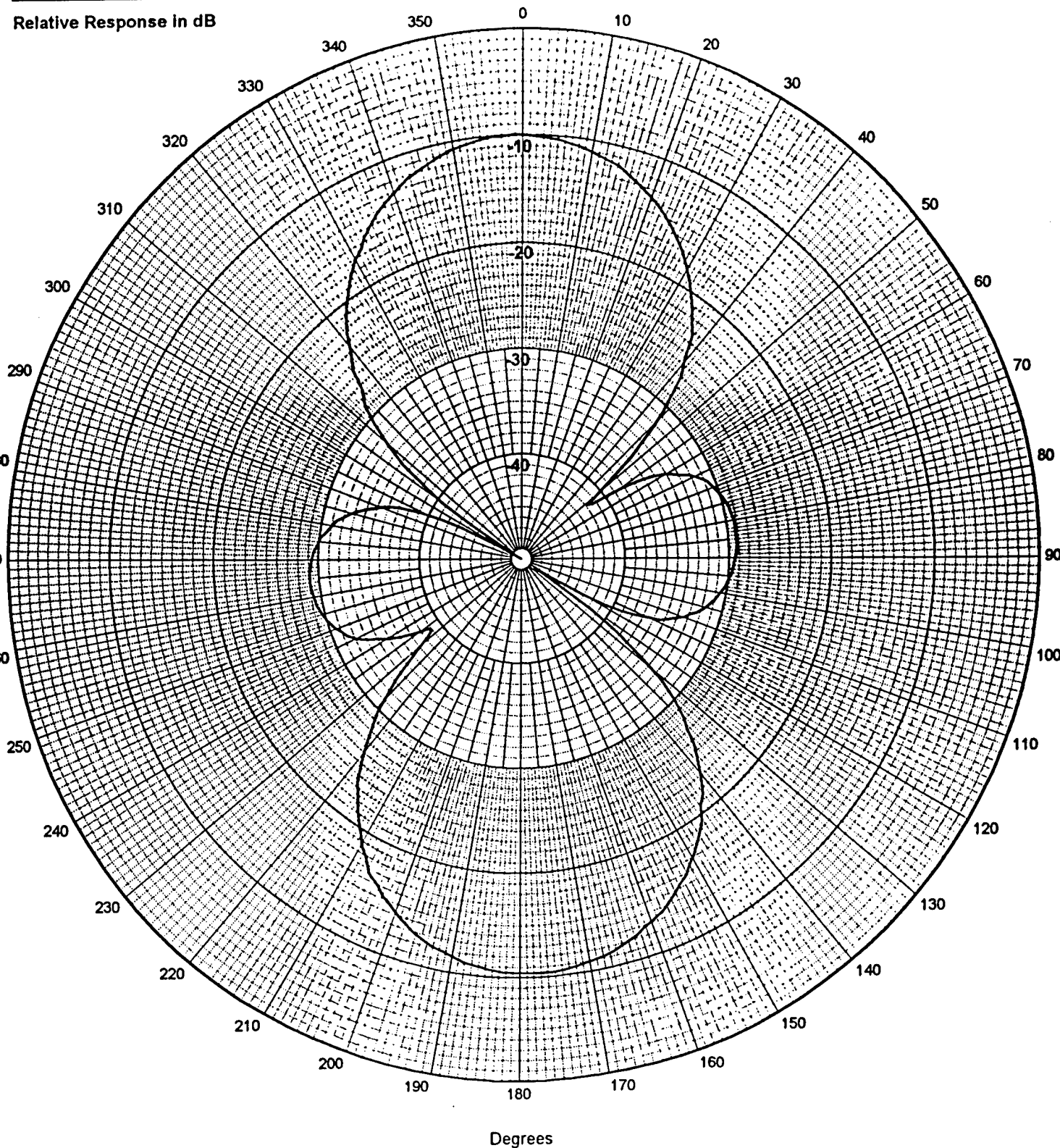




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB

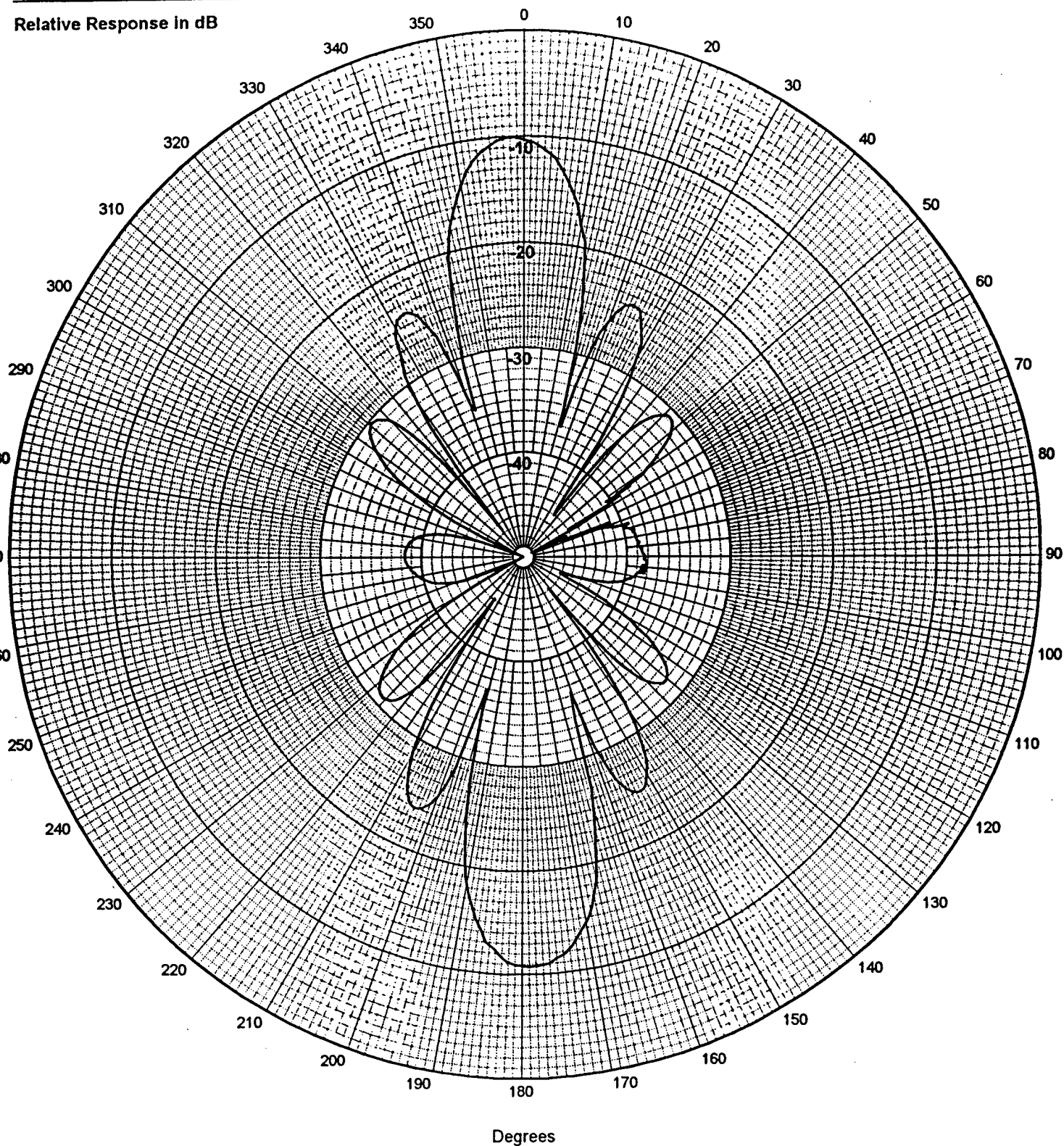




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

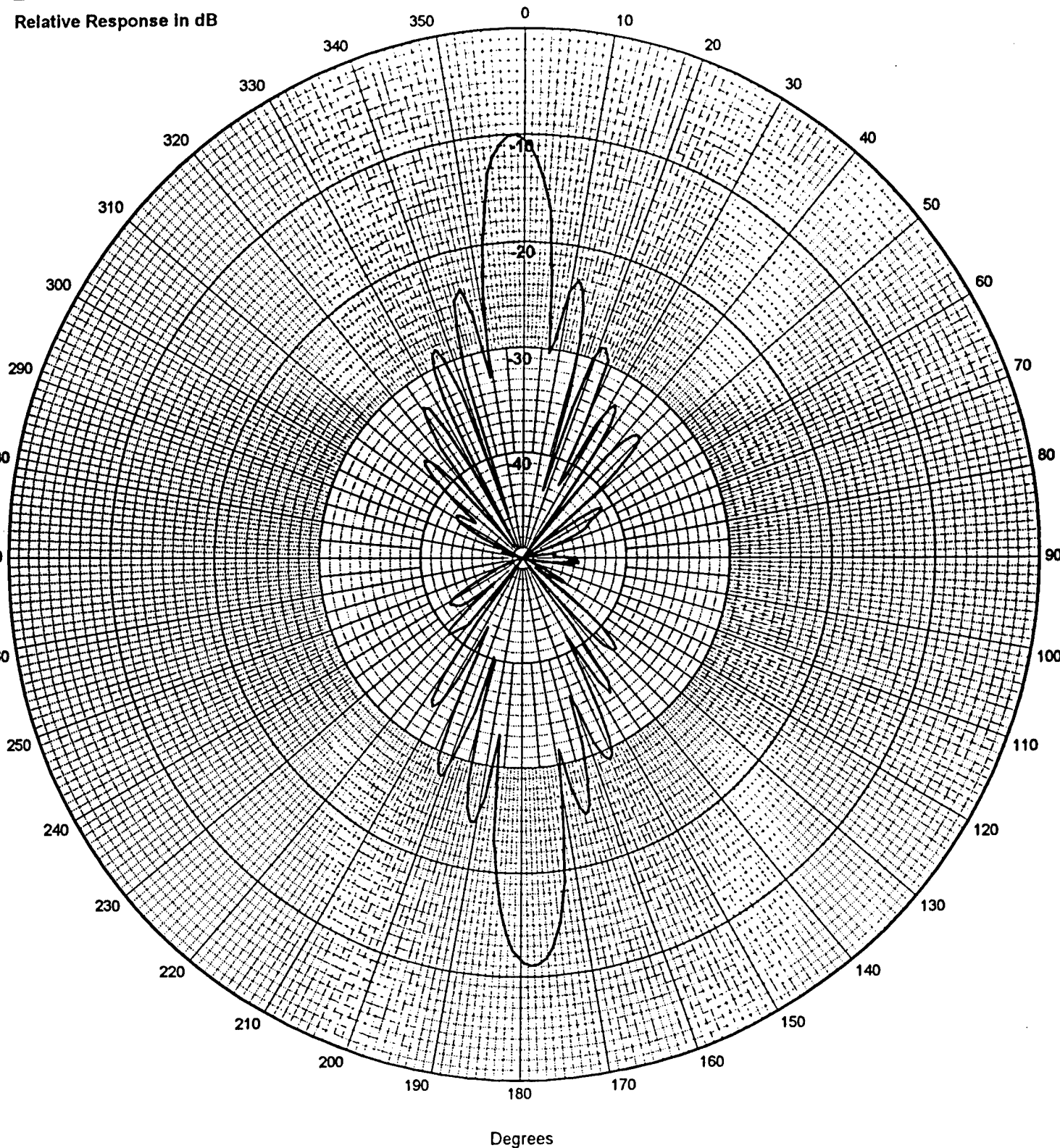
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

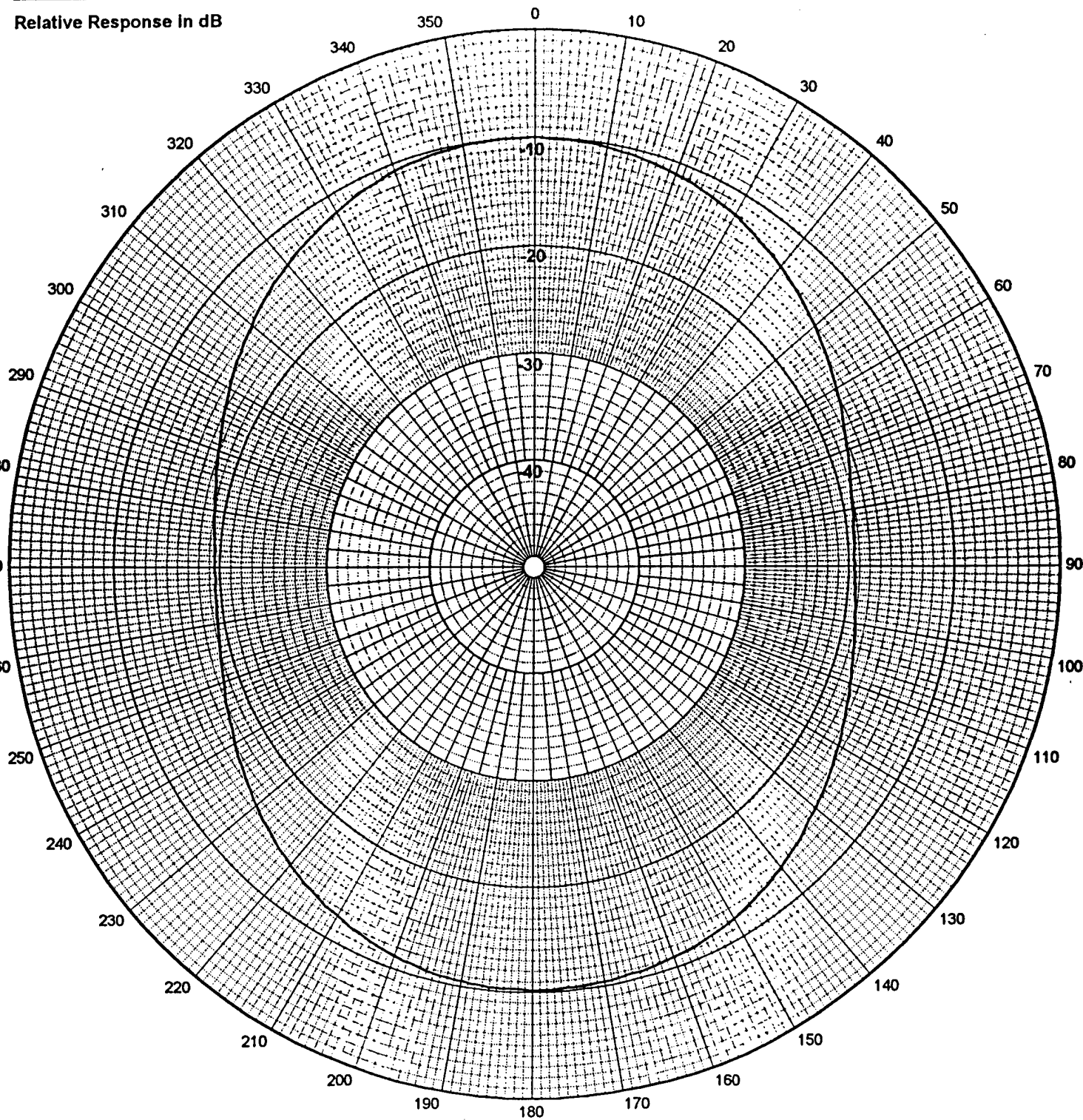
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response In dB

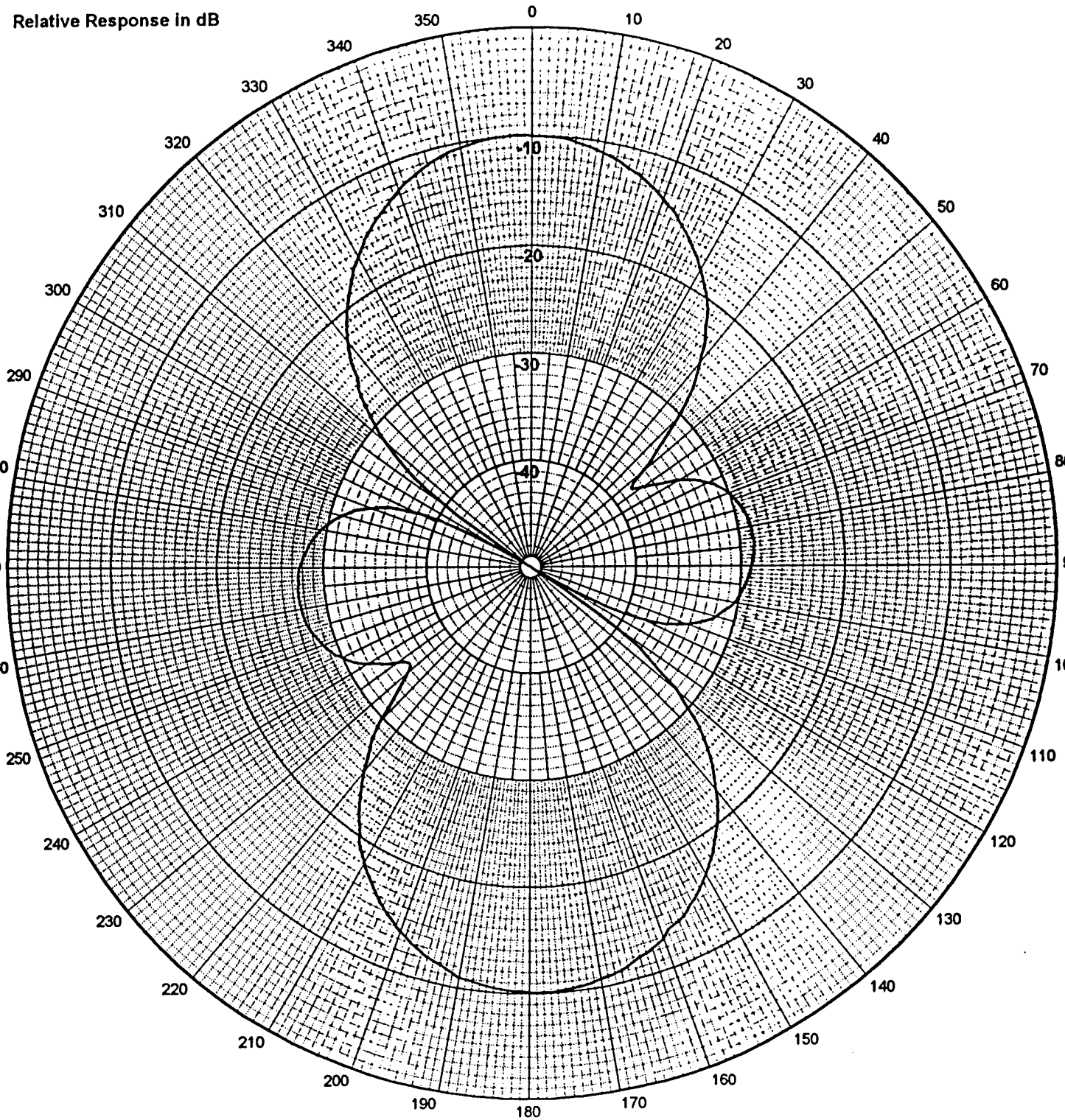


Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB

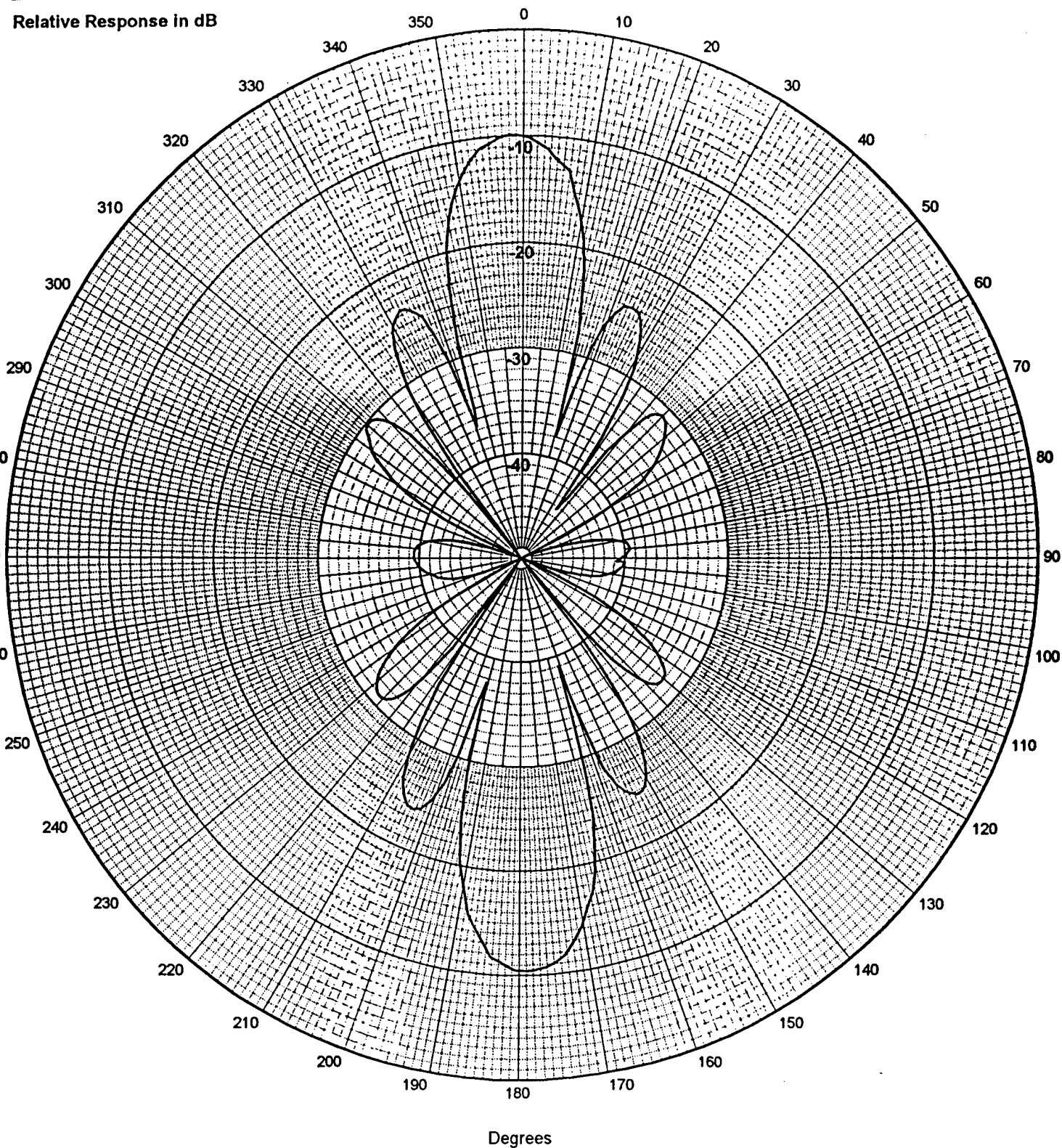


Degrees



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

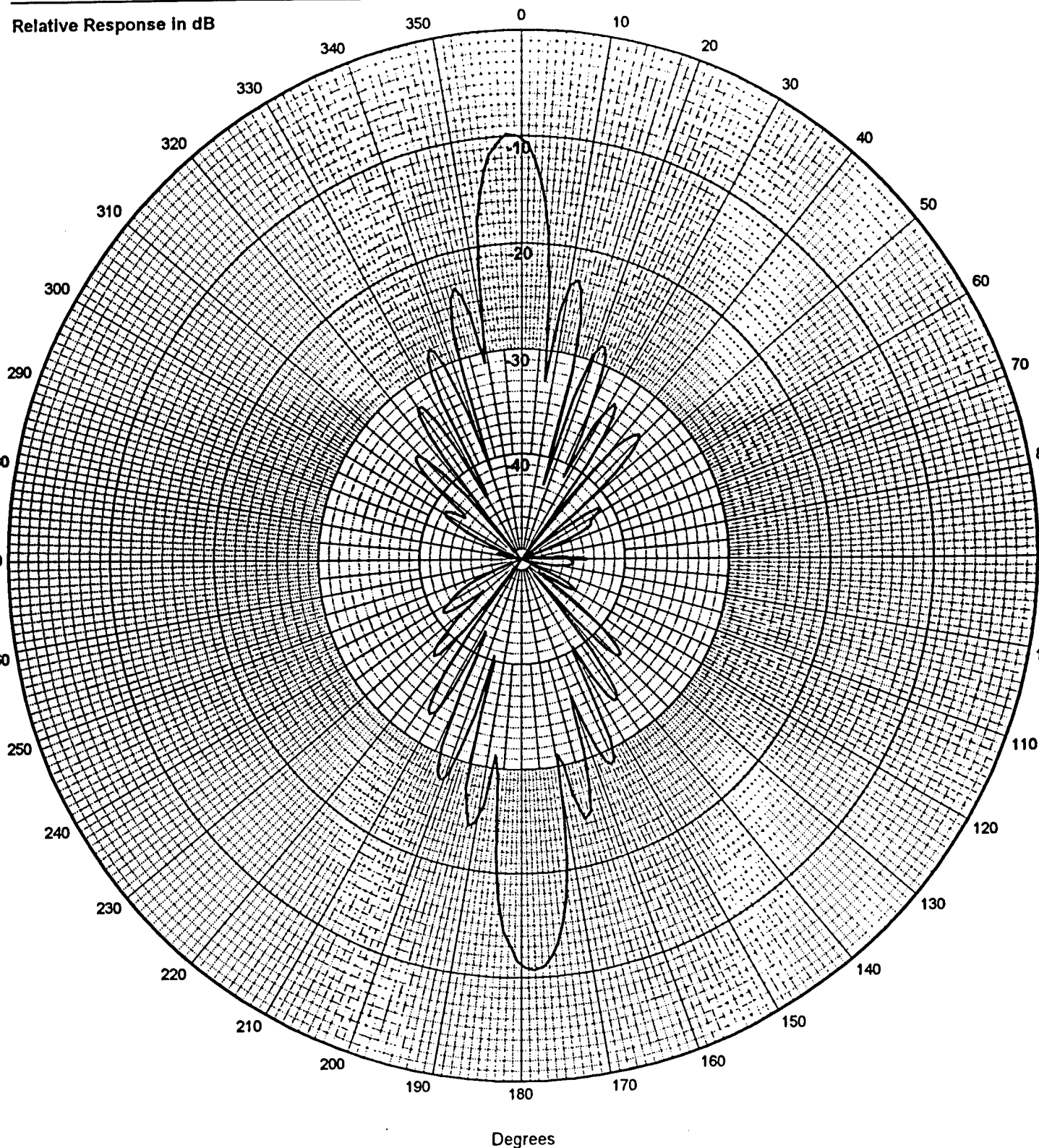




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

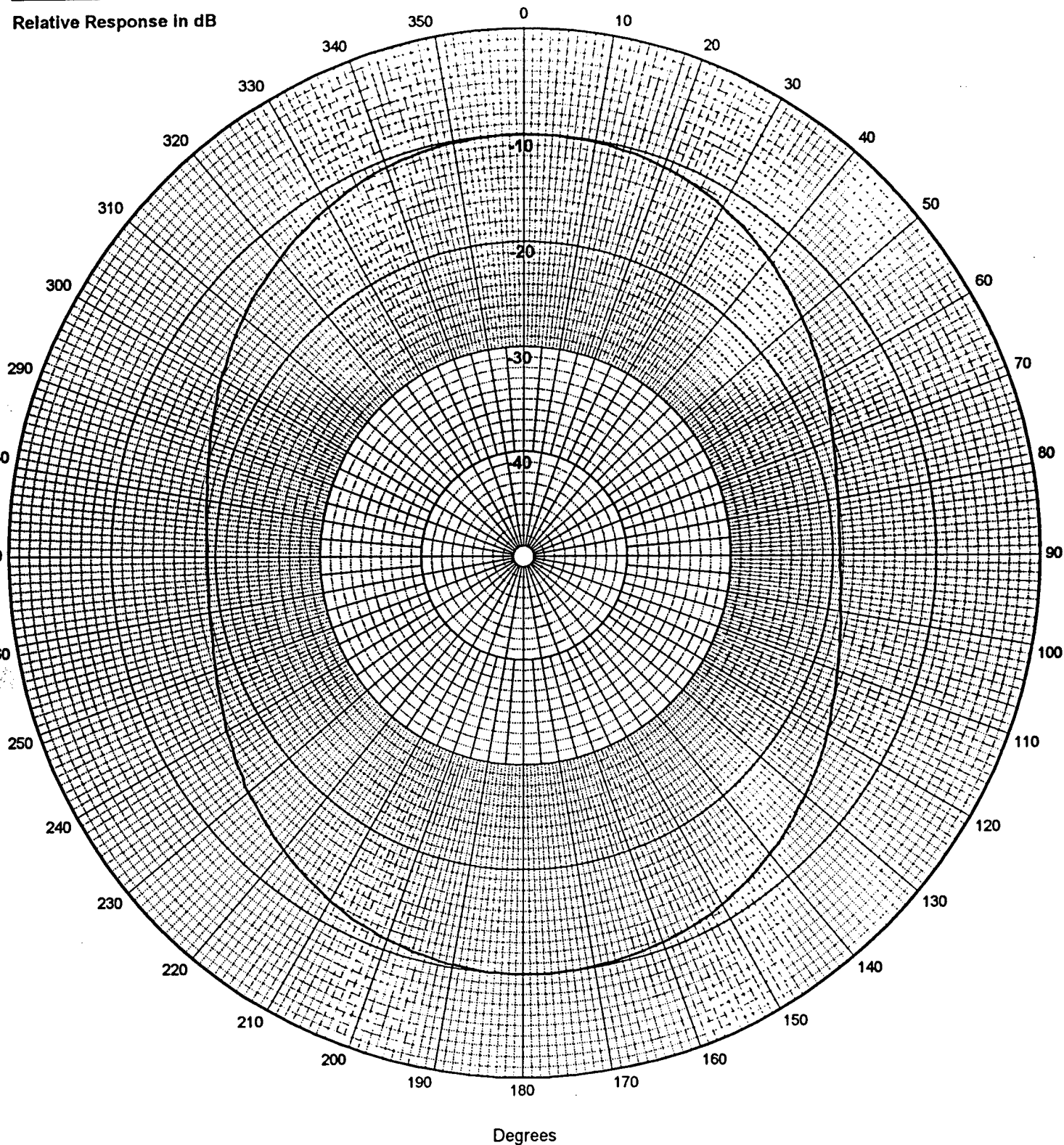
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

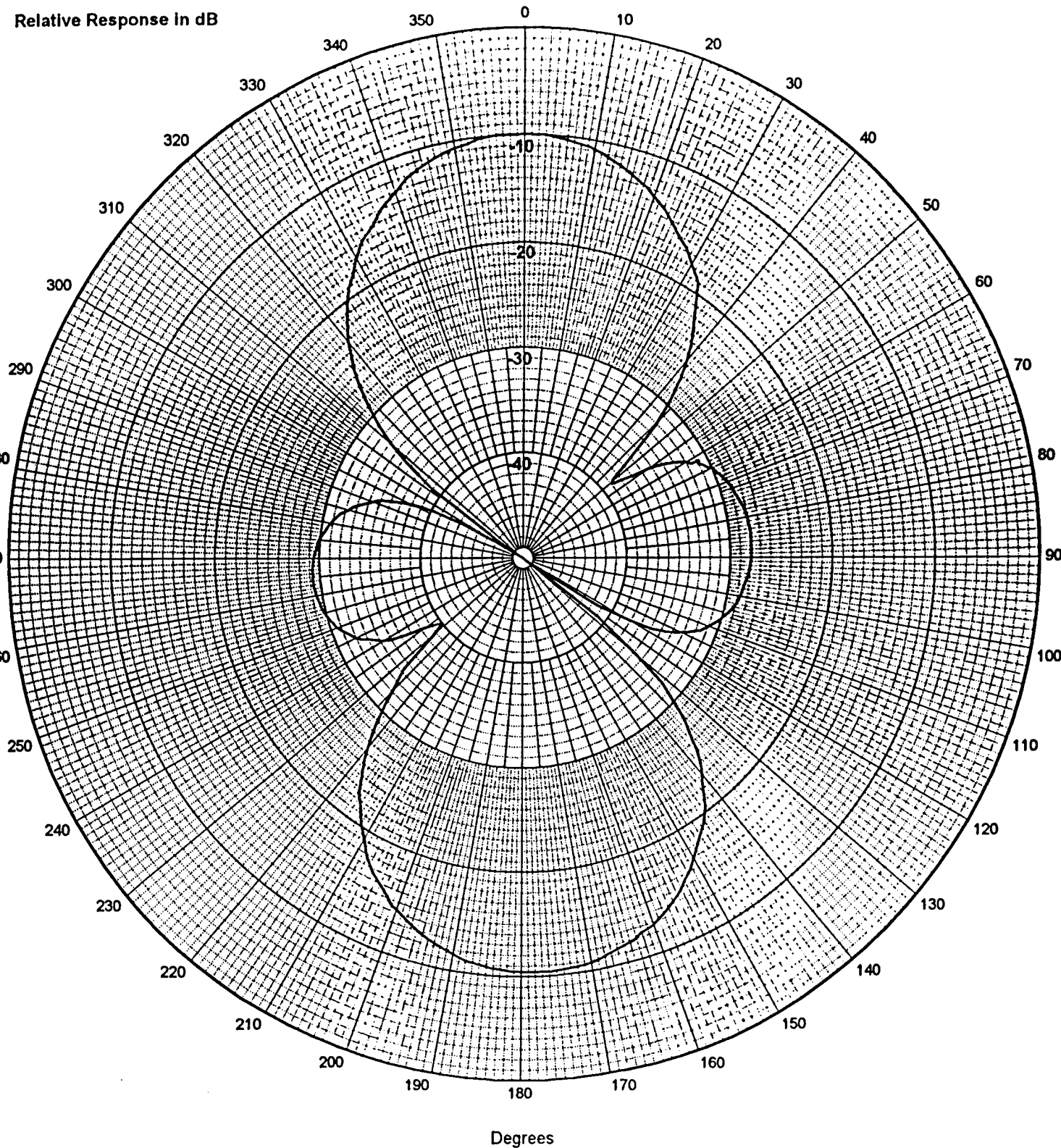
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

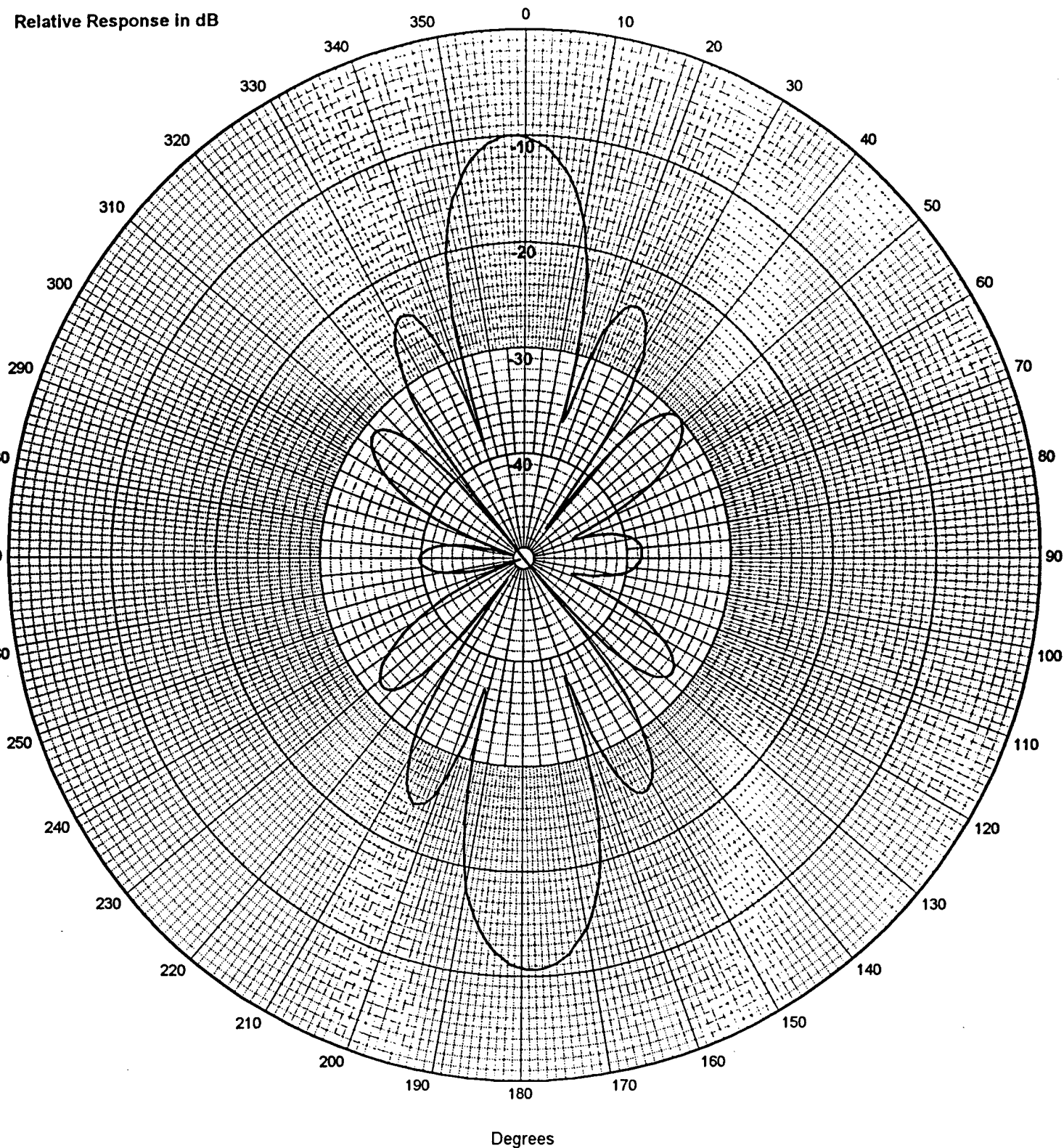
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

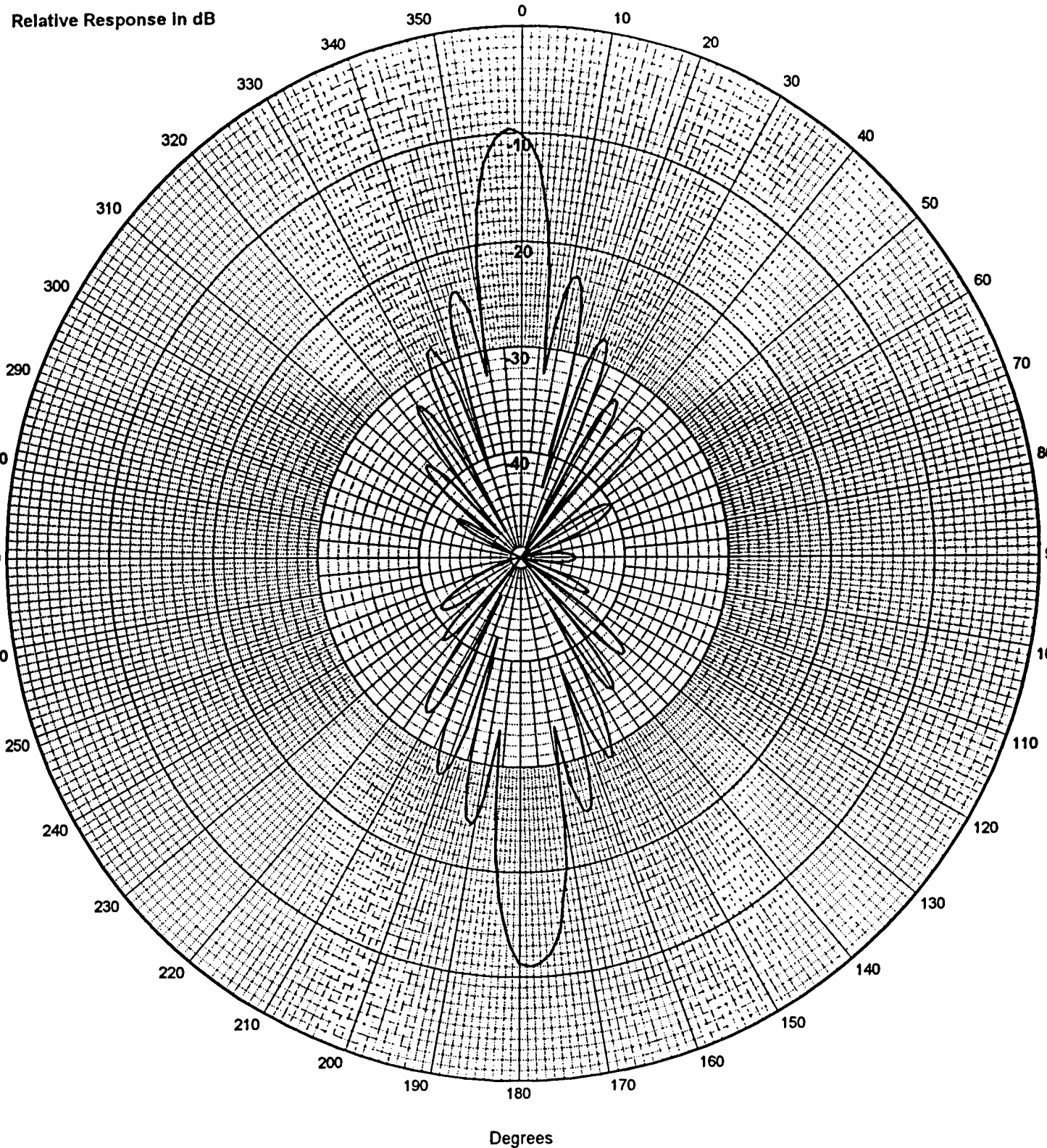
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB





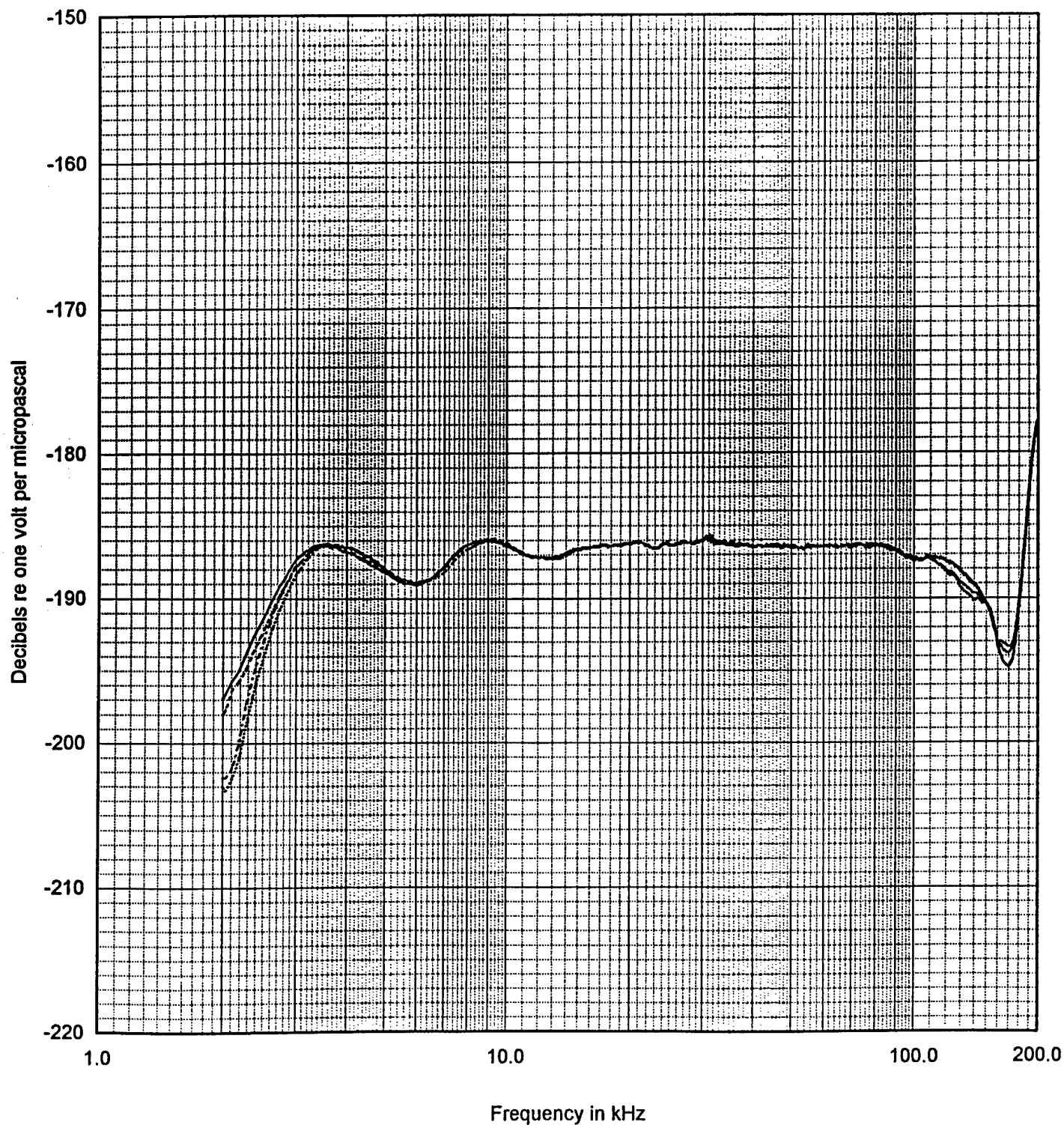
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-51

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - 16 kPa ( 1.6 m) After Pressure



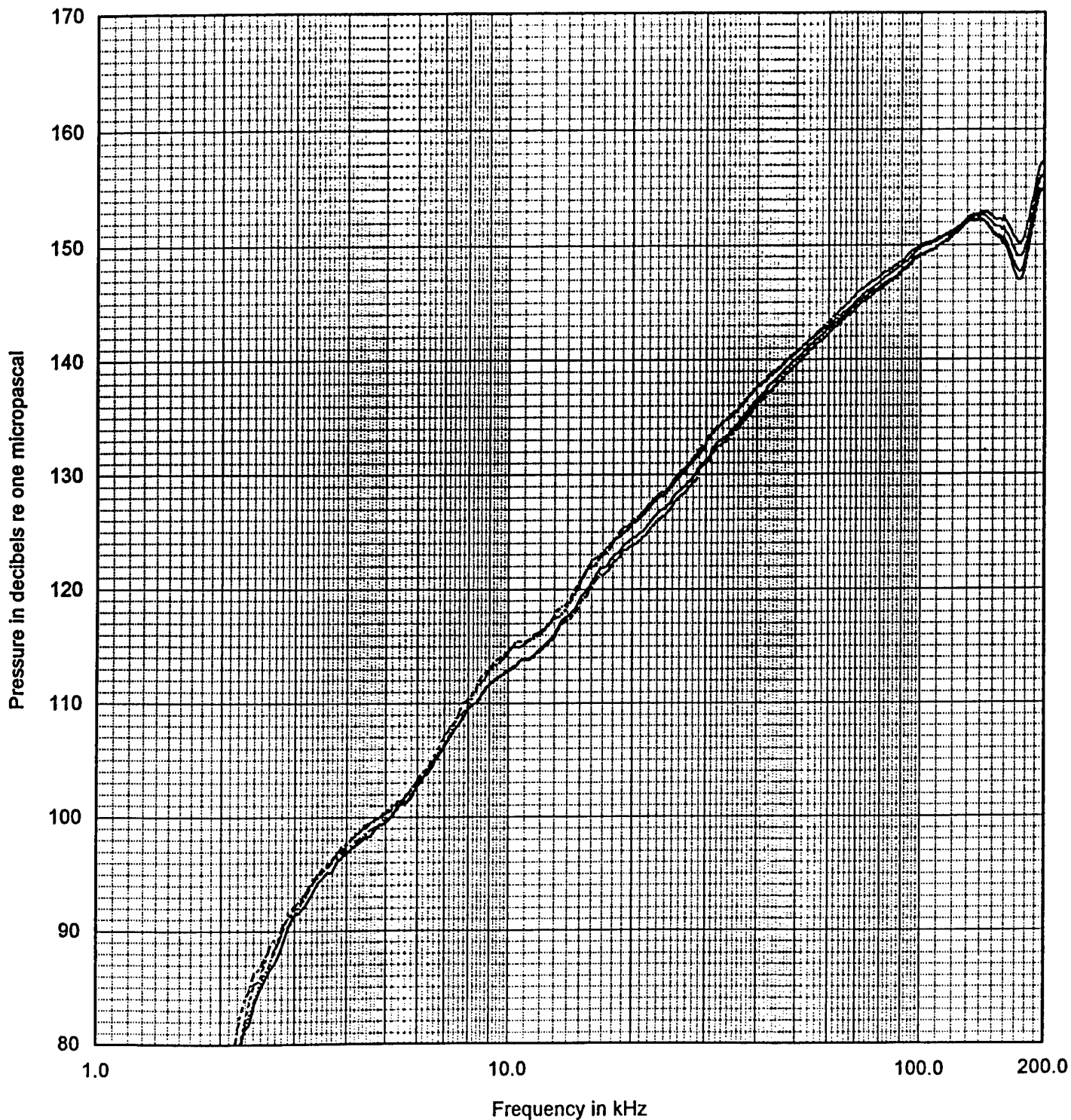
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-51

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
- · - · 6895 kPa ( 703.1 m)  
- · - · 16 kPa ( 1.6 m) After Pressure



30°  
330°20°  
340°10°  
350°

0

300°  
10°240°  
20°

30°

USRD NO:

0727-75

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Transmit

Before Pressure

XY Plane

10 kHz

75

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

30° 20° 10° 0° 350° 340° 330° 320° 310° 300°

USRD NO: 0727-76  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

30°  
20°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

210°  
150°

200°  
160°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

76  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
Before Pressure  
XY Plane  
20 kHz

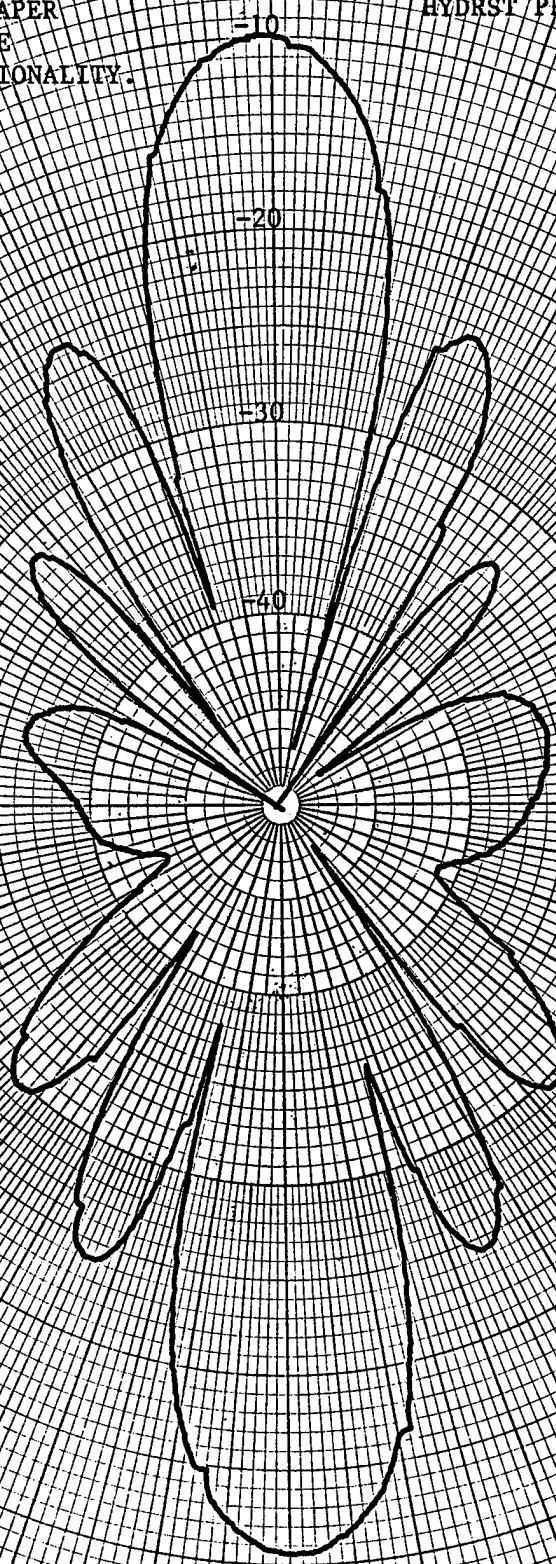


30° 20° 10° 0° 350° 340° 330°  
330° 340° 350° 0° 10° 20° 30°

USRD NO: 0727-77  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

77  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
Before Pressure  
XY Plane  
50 kHz



30° 20° 10° 0° 350° 340° 330° 10° 20° 30°

USRD NO: 0727-78  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER STRETCH AND CENTERING. USE SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

00° 310°

0° 300°

70° 290°

50° 80°

90° 70°

00° 60°

110° 250°

120° 240°

130° 230°

140° 220°

320° 40°

310° 50°

300° 60°

290° 70°

280° 80°

270° 90°

260° 100°

250° 110°

240° 120°

230° 130°

220° 140°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

78

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
Before Pressure  
XY Plane  
100 kHz

150° 210° 160° 200° 170° 190° 180° 170° 200° 160° 150°

30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO:

0727-79

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

3448 kPa (351.6 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°10°  
20°50°  
810°30°  
00°70°  
290°80°  
80°90°  
170°00°  
260°110°  
250°120°  
240°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB

USRD NO:

0727-80

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

3448 kPa (351.6 m)

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Transmit

XY Plane

20 kHz



30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO:

0727-81

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

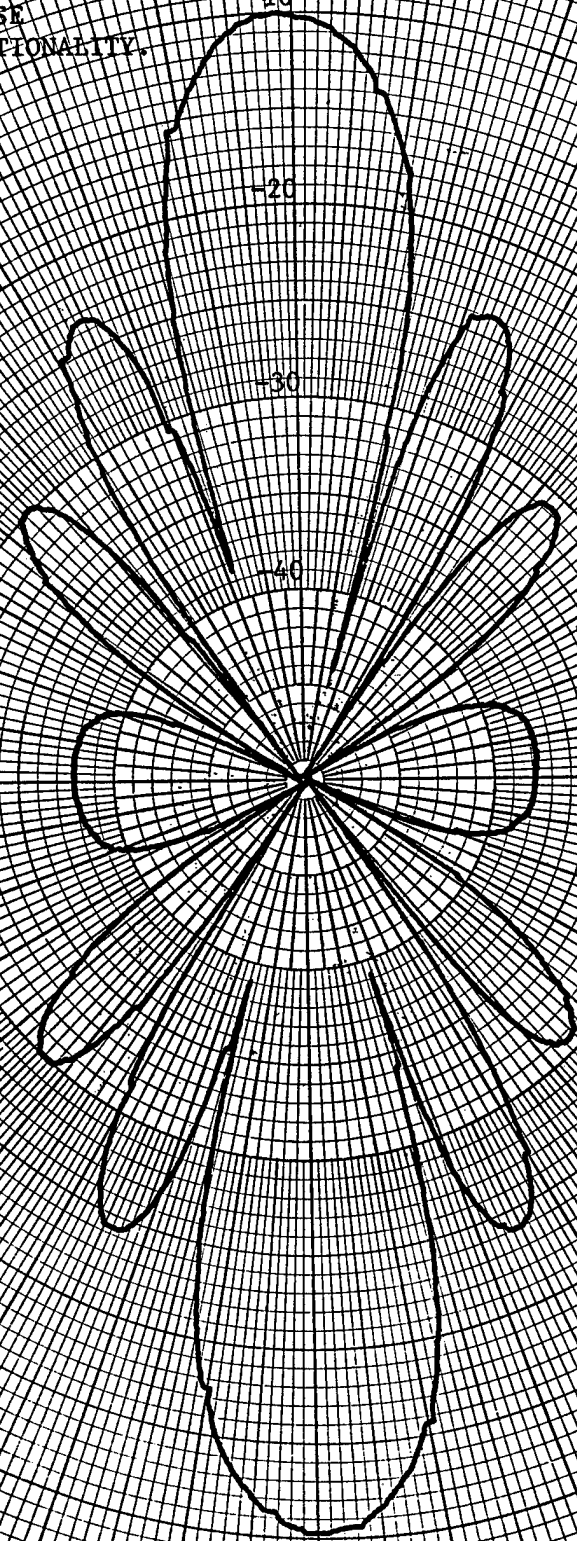
4°C

HYDRST PRESS:

3448 kPa (351.6 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

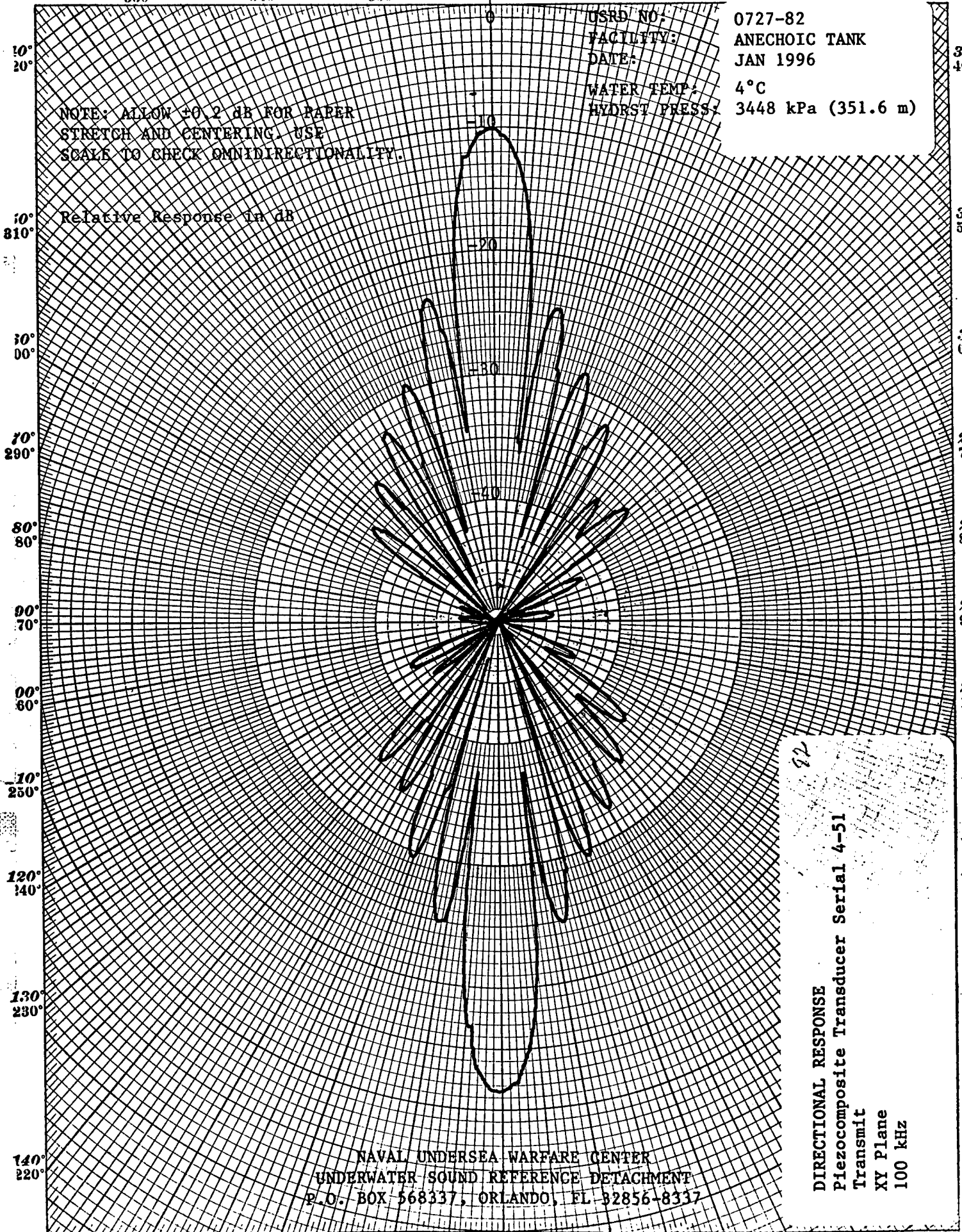
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
XY Plane  
50 kHz

30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-82  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

92  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
XY Plane  
100 kHz



30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

USRD NO: 0727-83  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

83  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

USRD NO:

0727-84

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

6895 kPa (703.1 m)

Relative Response in dB

30°  
810°10°  
30°70°  
290°80°  
80°90°  
70°00°  
-60°110°  
250°120°  
240°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Transmit

XY Plane

20 kHz

84

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

USRD NO:

0727-85

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

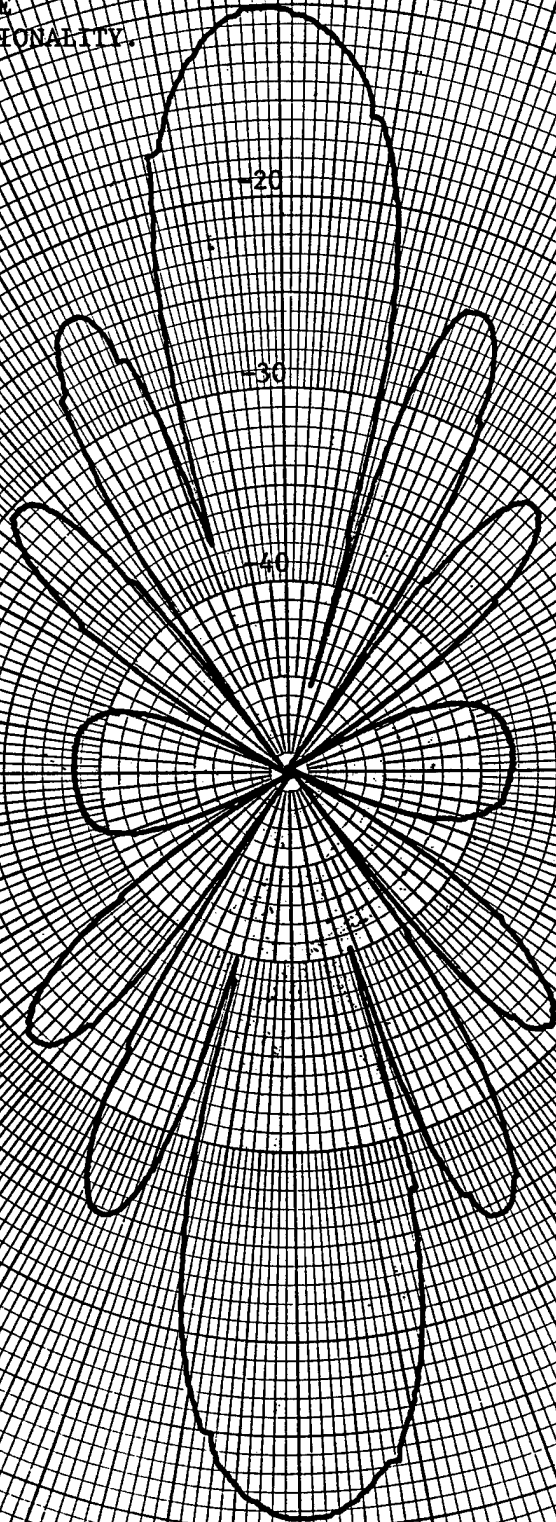
4°C

HYDRST PRESS:

6895 kPa (703.1 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Transmit

XY Plane

50 kHz

85



30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO:

0727-86

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

6895 kPa (703.1 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

0°  
310°0°  
0°70°  
290°80°  
30°90°  
70°90°  
30°110°  
250°120°  
140°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

86  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
XY Plane  
100 kHz

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

40°  
20°

50°  
810°

60°  
00°

70°  
290°

80°  
80°

90°  
70°

00°  
60°

10°  
250°

120°  
240°

130°  
230°

140°  
220°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-87  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

87  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51  
Transmit  
After Pressure  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

150°  
210°

160°  
200°

170°  
190°

180°  
180°

190°  
170°

200°  
160°

210°  
150°



30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0727-88  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

0°  
10°  
20°  
30°  
40°  
50°  
60°  
70°  
80°  
90°  
100°  
110°  
120°  
130°  
140°  
150°  
160°  
170°  
180°  
190°  
200°  
210°  
220°  
230°  
240°  
250°  
260°  
270°  
280°  
290°  
300°  
310°  
320°

320°  
40°  
310°  
50°  
300°  
60°  
290°  
70°  
280°  
80°  
270°  
90°  
260°  
100°  
250°  
110°  
240°  
120°  
230°  
130°  
140°  
220°  
150°  
160°  
170°  
180°  
190°  
200°  
210°  
220°  
230°  
240°  
250°  
260°  
270°  
280°  
290°  
300°  
310°  
320°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

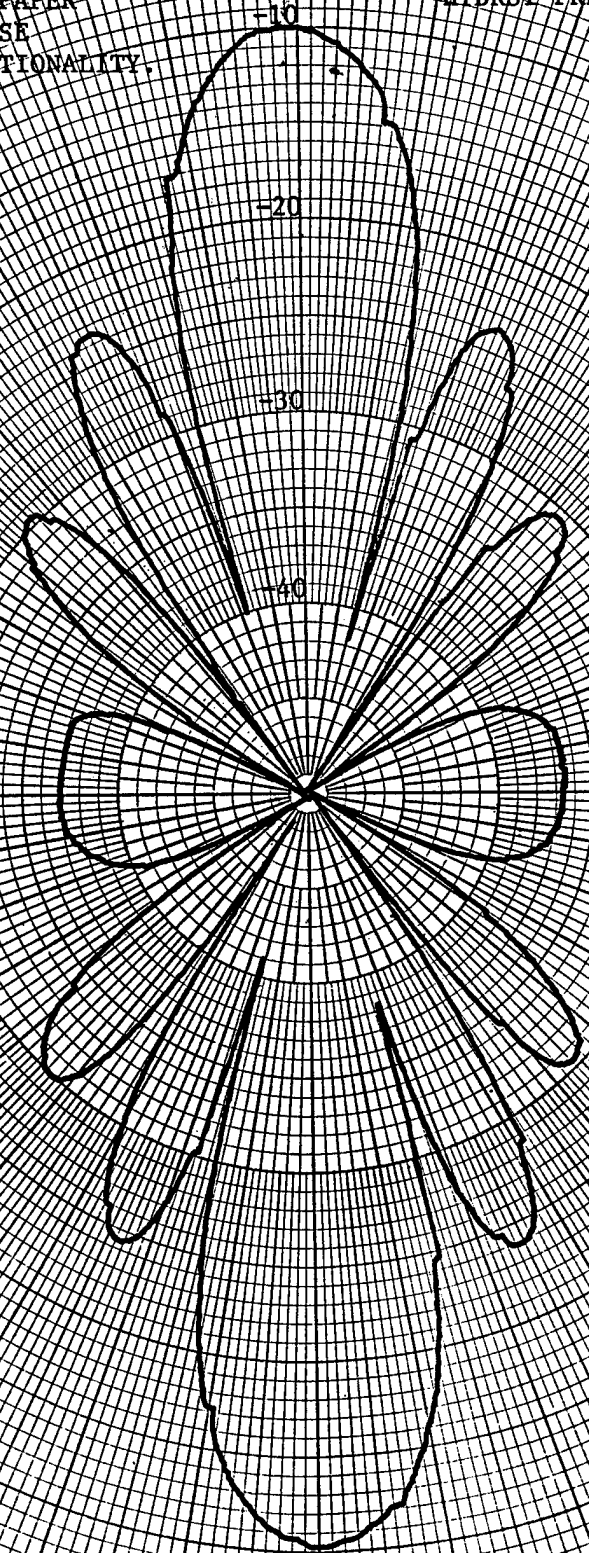
88  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-5123  
Transmit  
After Pressure  
XY Plane  
20 kHz

30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-89  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

89  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-5174  
Transmit  
After Pressure  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

USRD NO: 0727-90  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

Relative Response in dB

30°  
310°

0°  
-10°

70°  
290°

80°  
30°

90°  
70°

100°  
80°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

90

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-51F  
Transmit  
After Pressure  
XY Plane  
100 kHz

150°  
210°

160°  
200°

170°  
190°

180°  
180°

190°  
170°

200°  
160°

210°  
150°



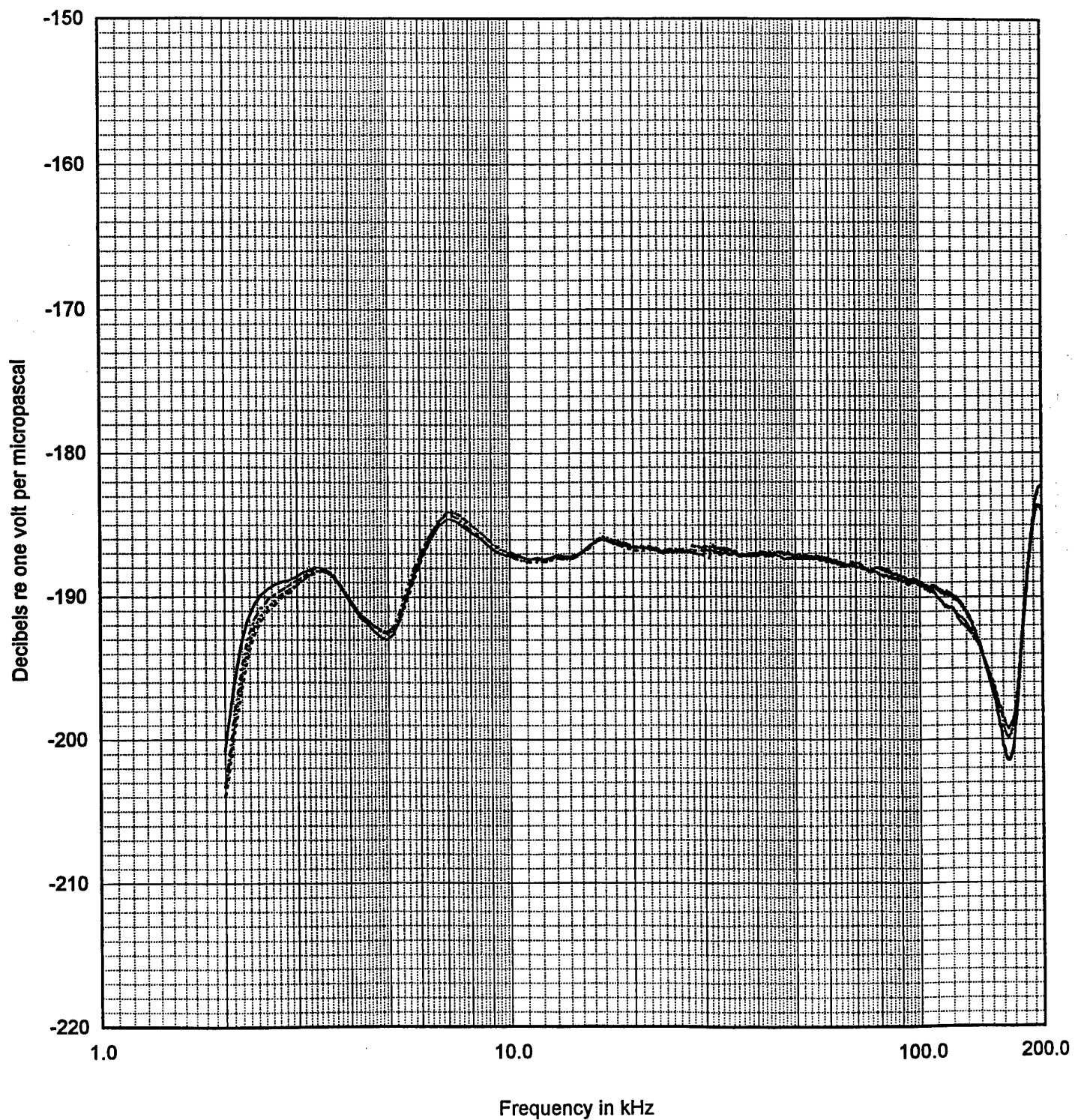
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-51

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
----- 16 kPa ( 1.6 m) After Pressure



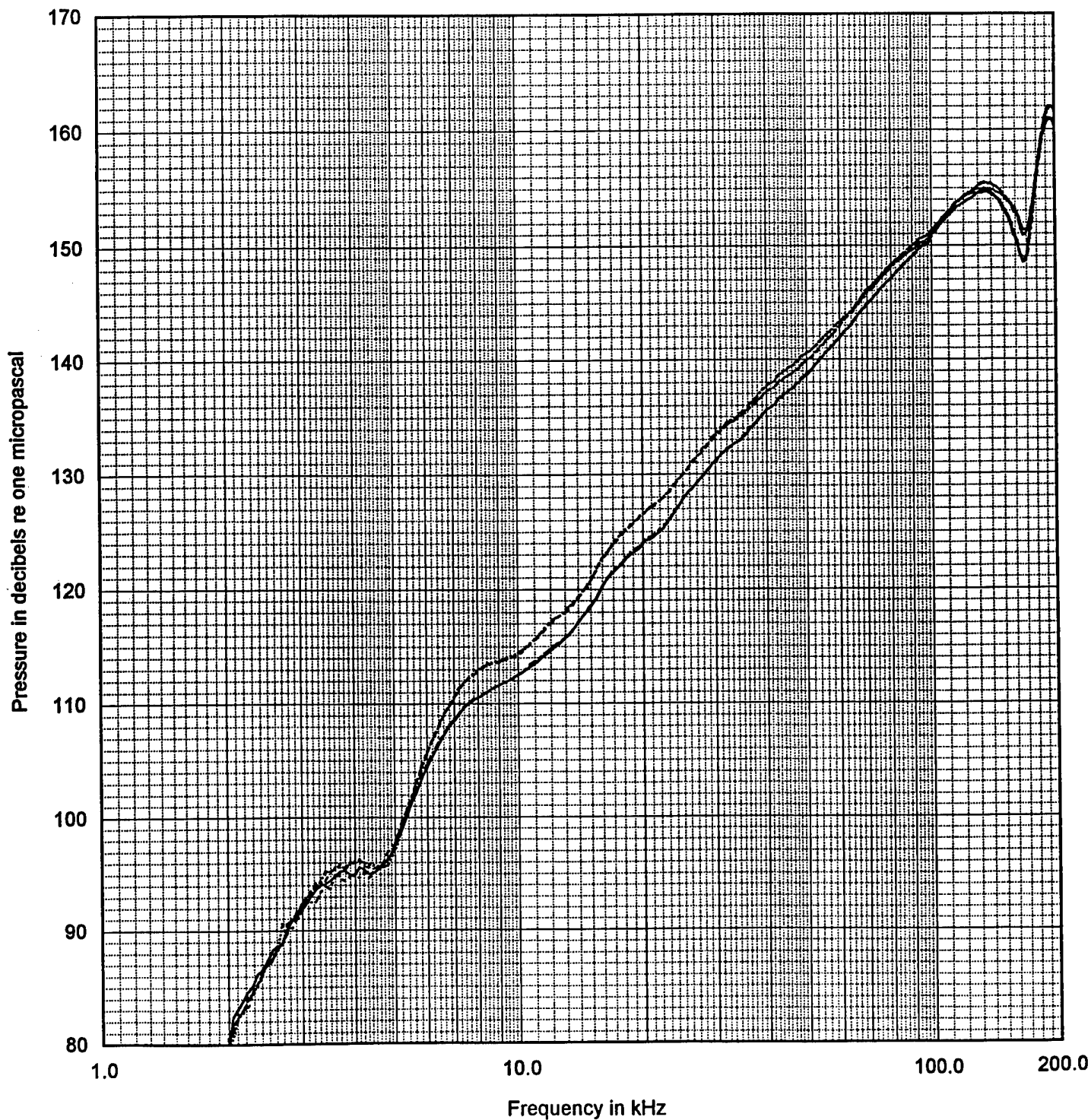
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-51

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- . - . 16 kPa ( 1.6 m) After Pressure





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USRD NO. 0727-93  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

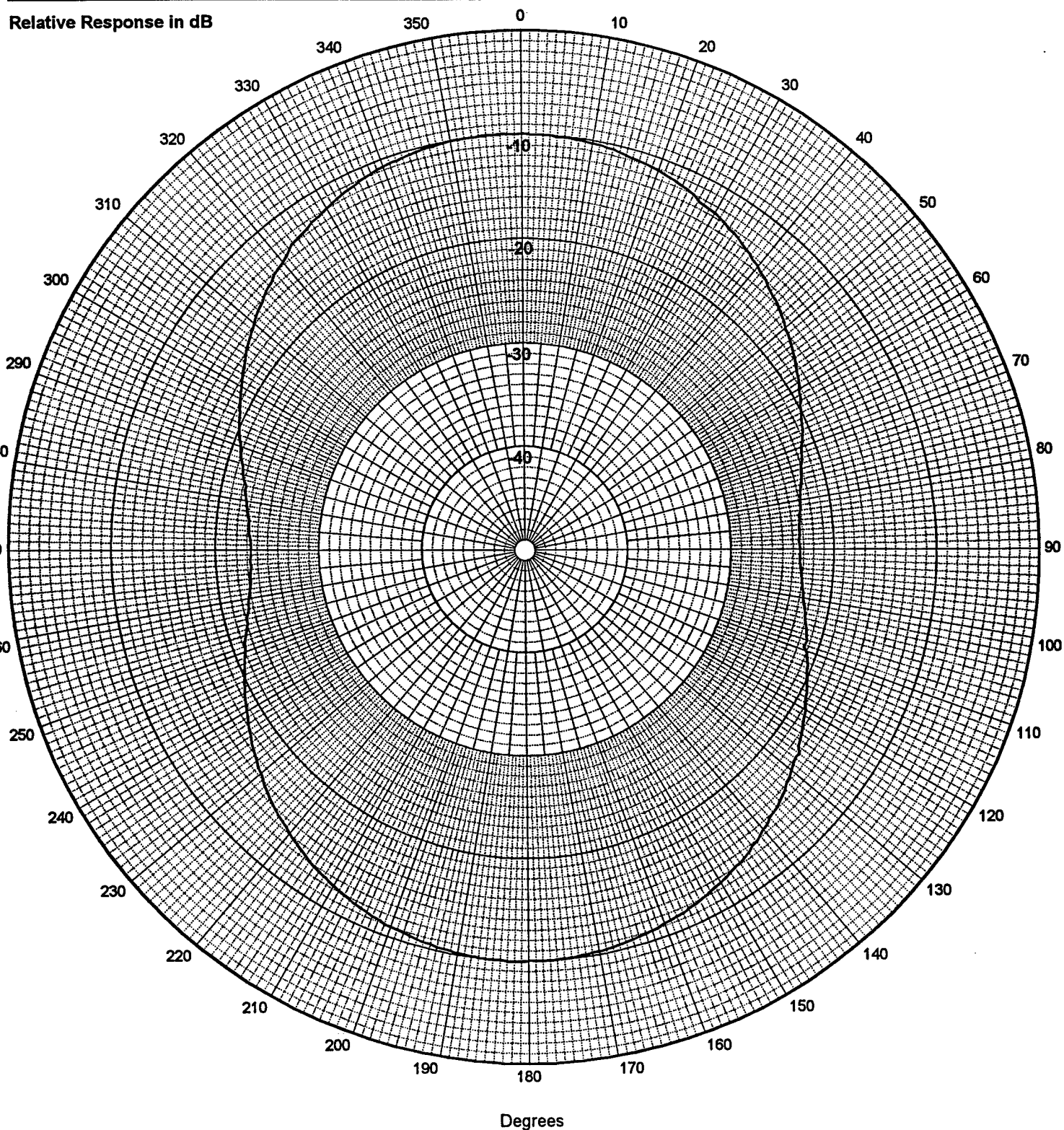
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

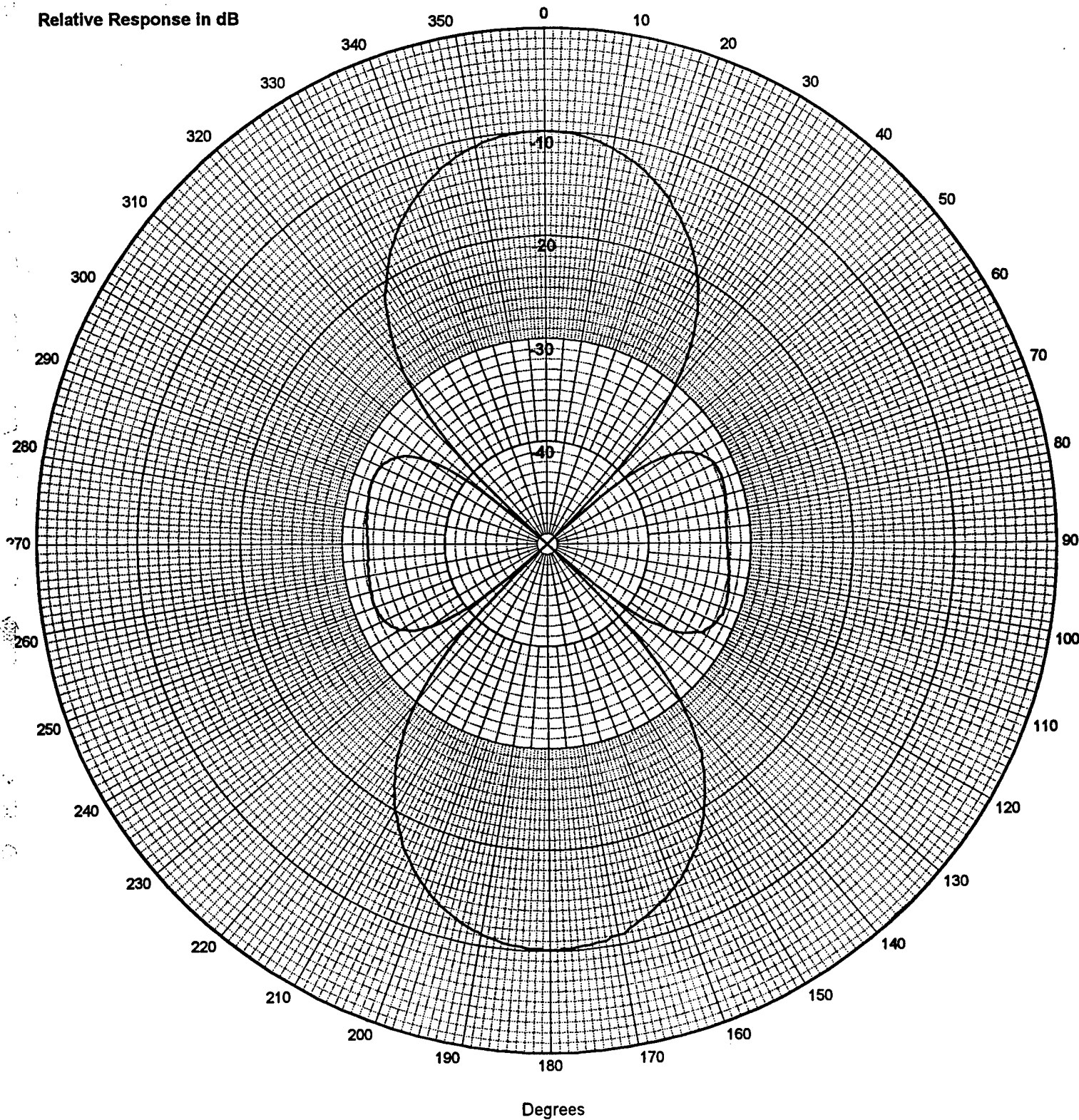
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

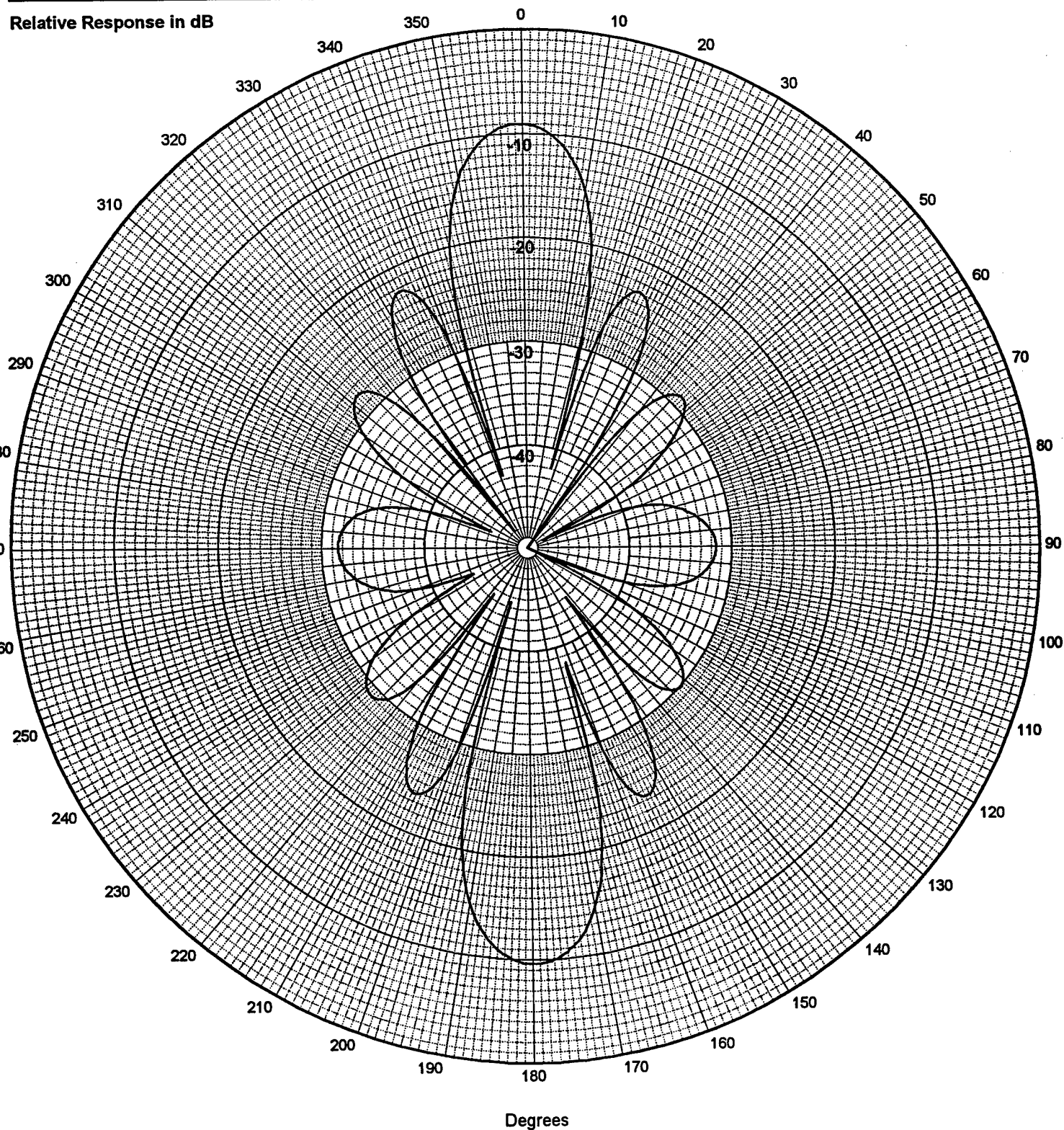
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

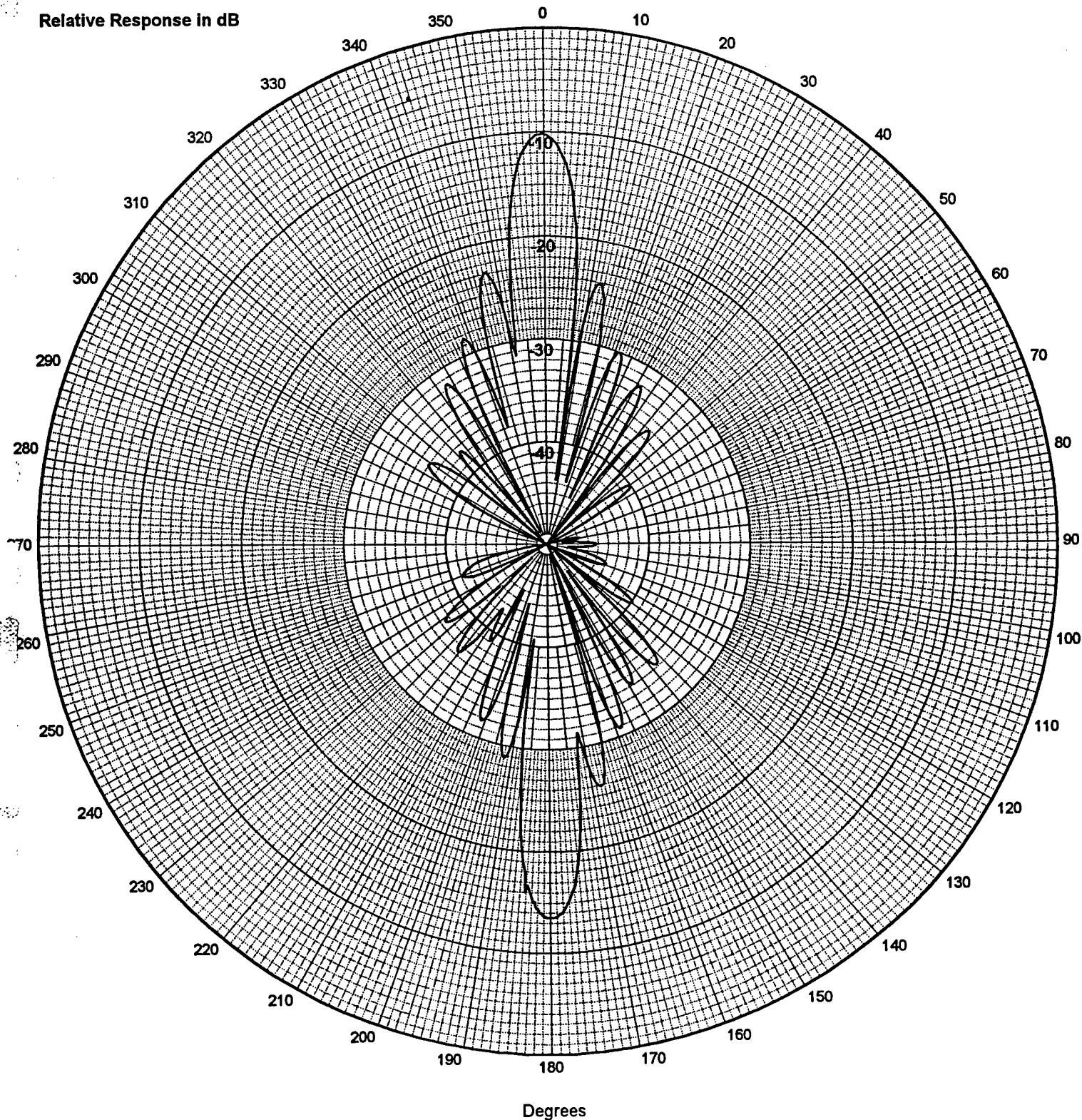
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB





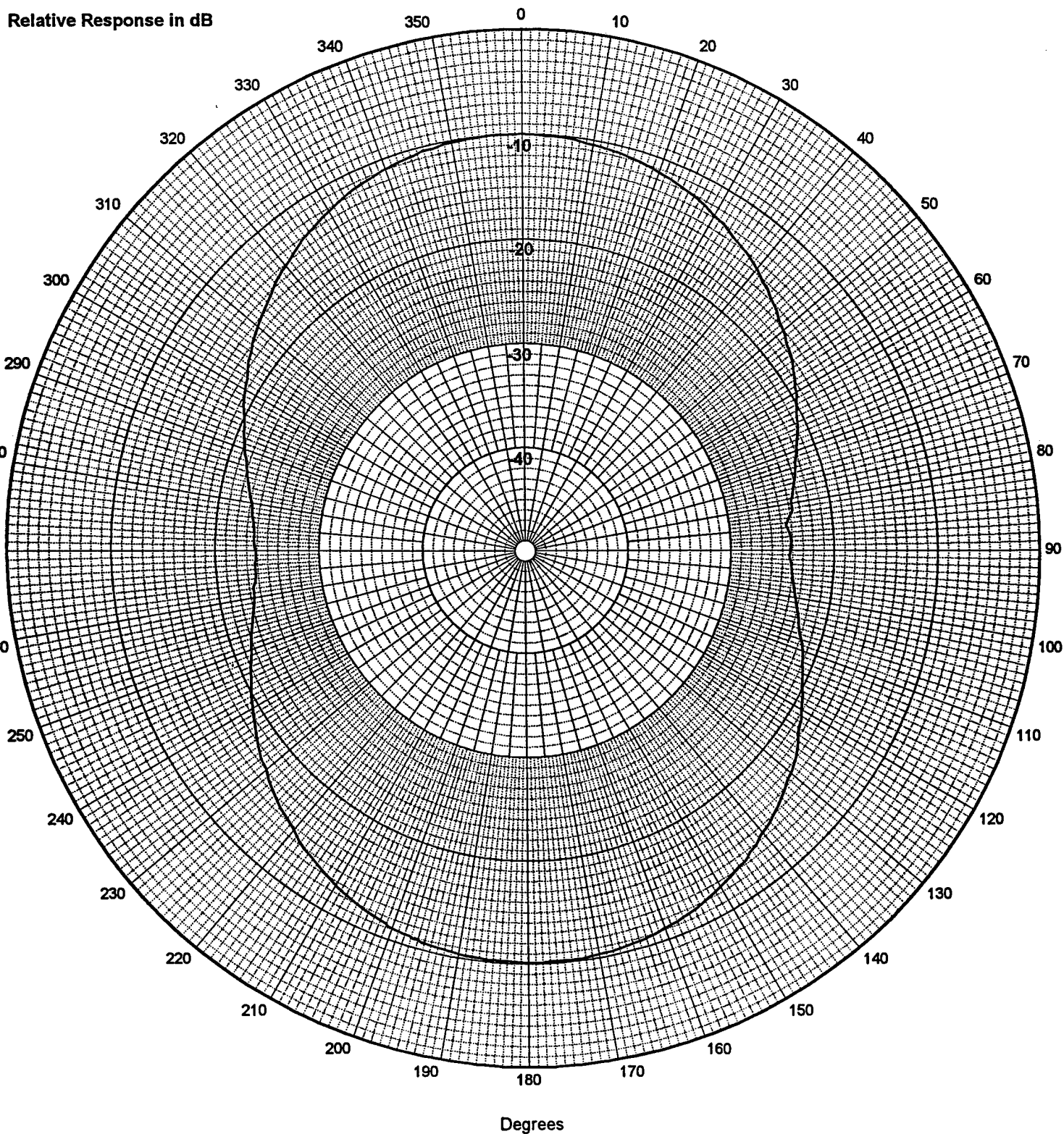
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0727-97  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB

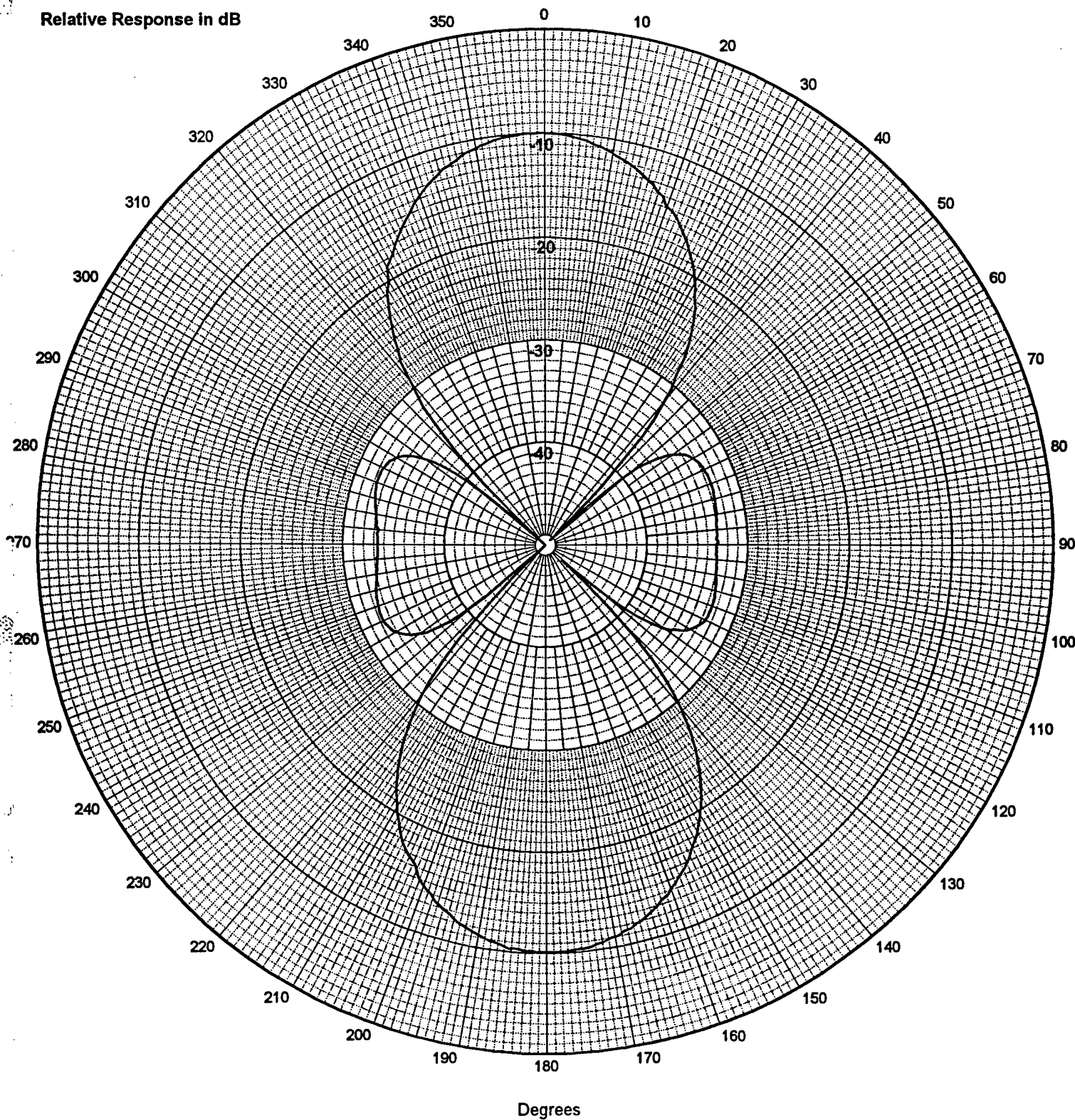




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



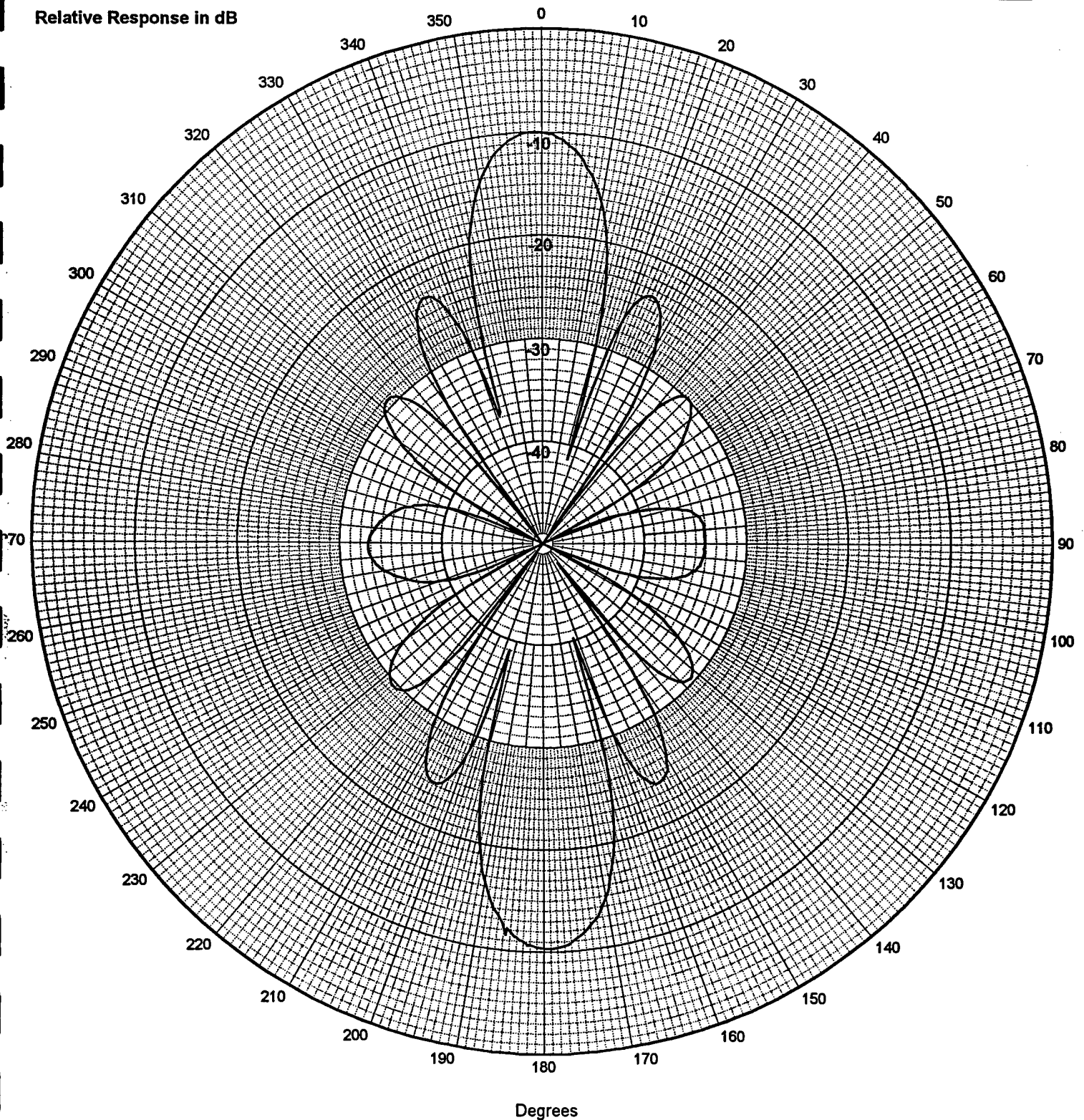
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-99  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

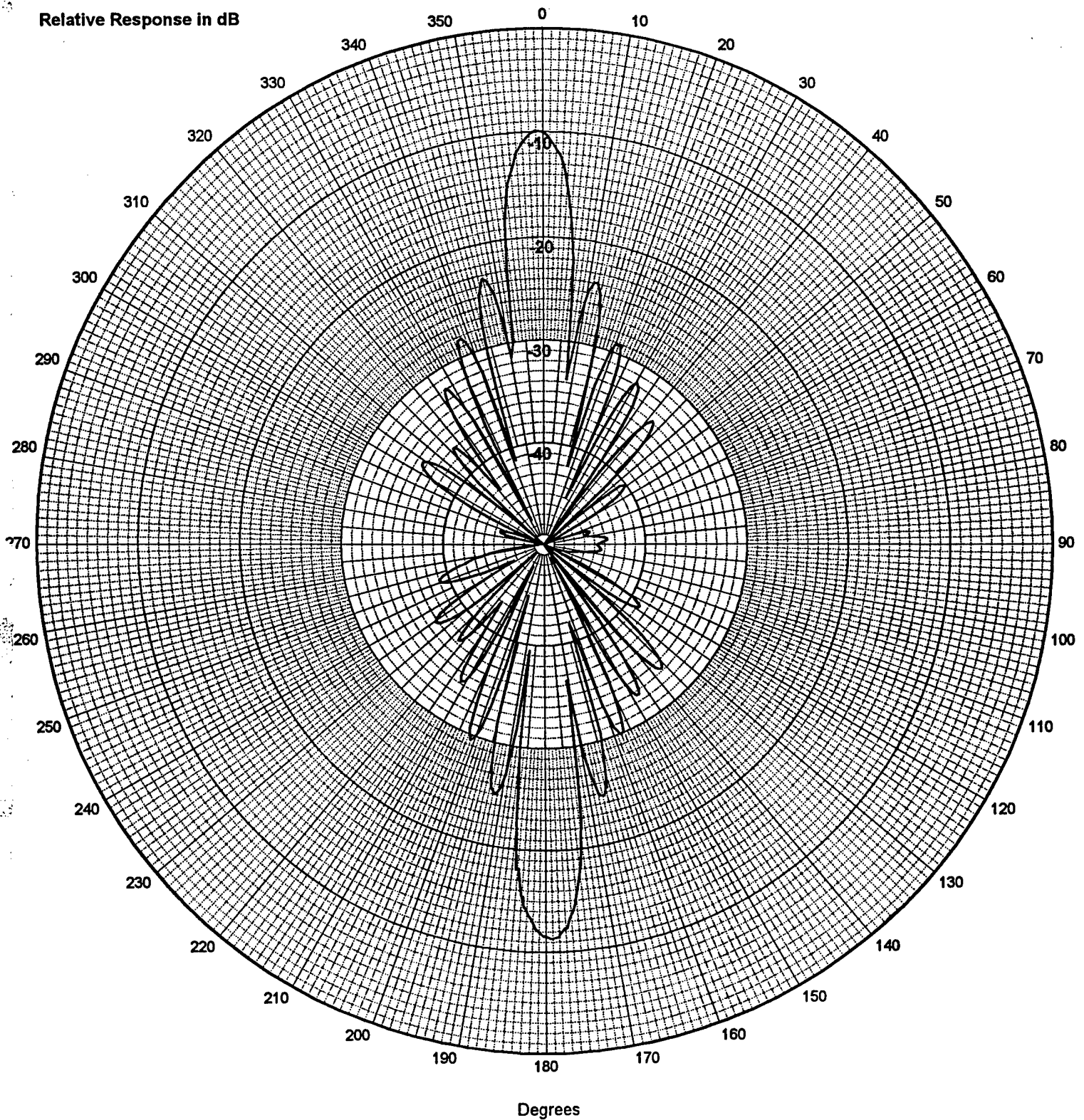
Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz



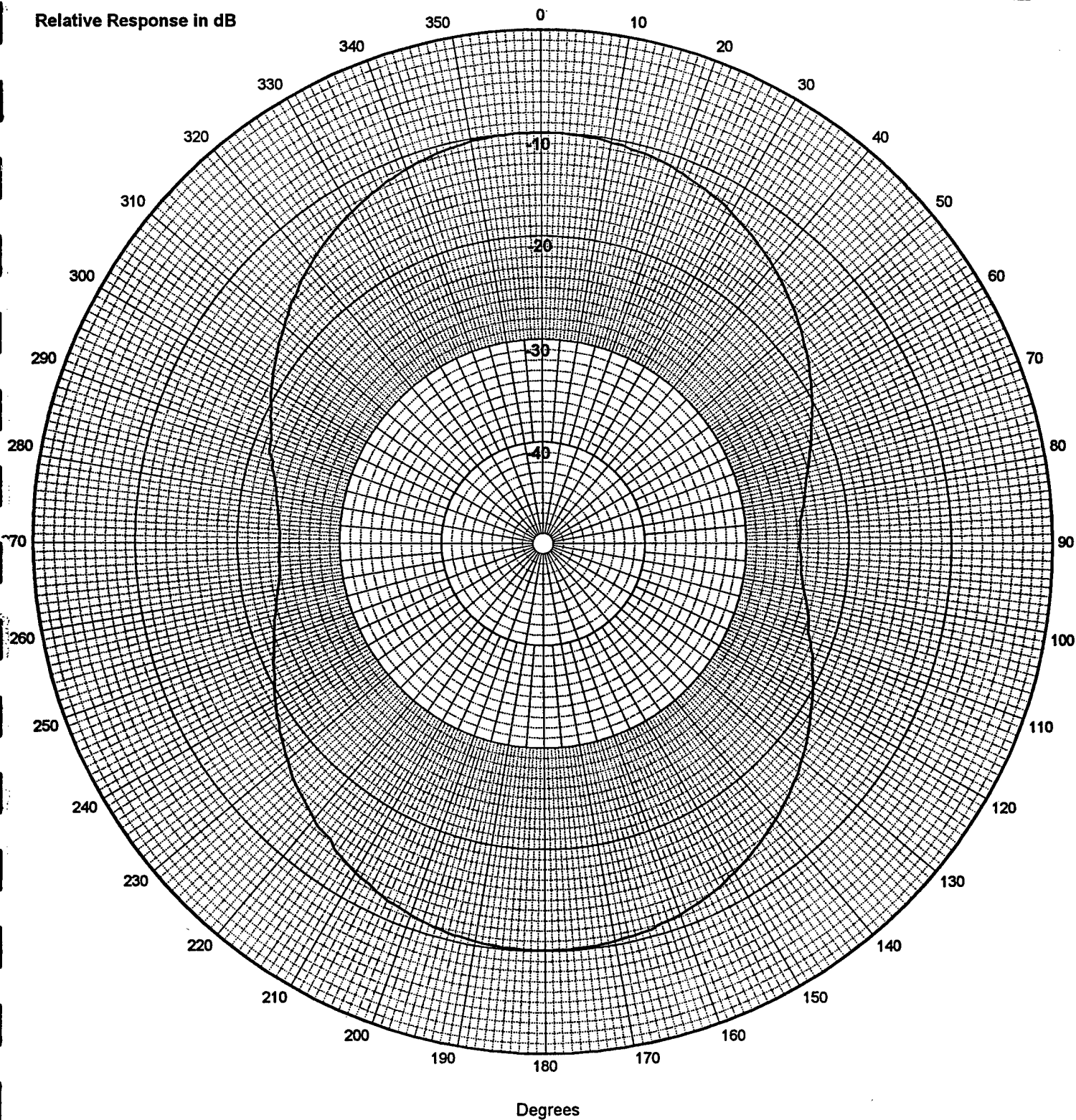
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0727-101  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB

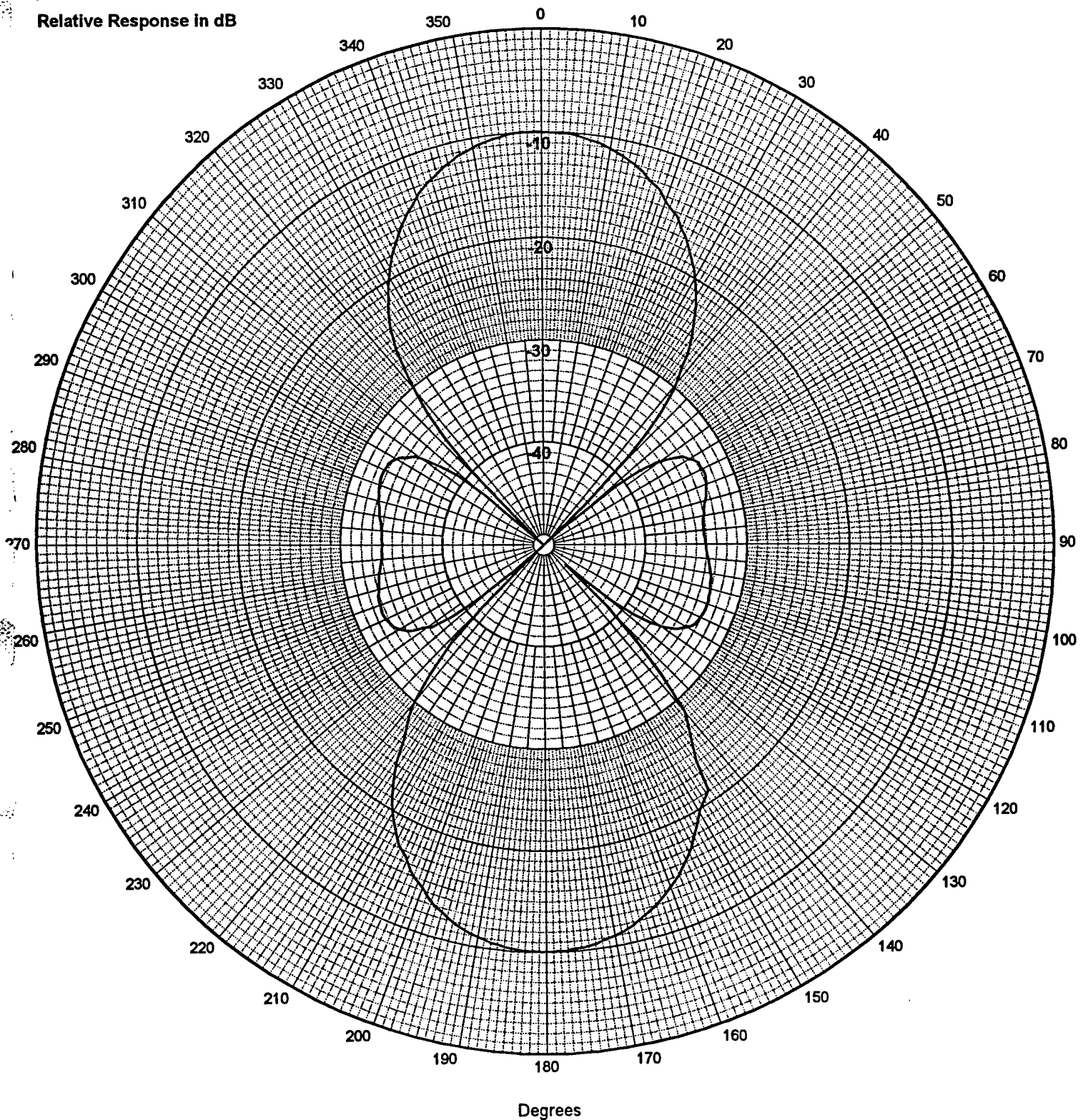




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB





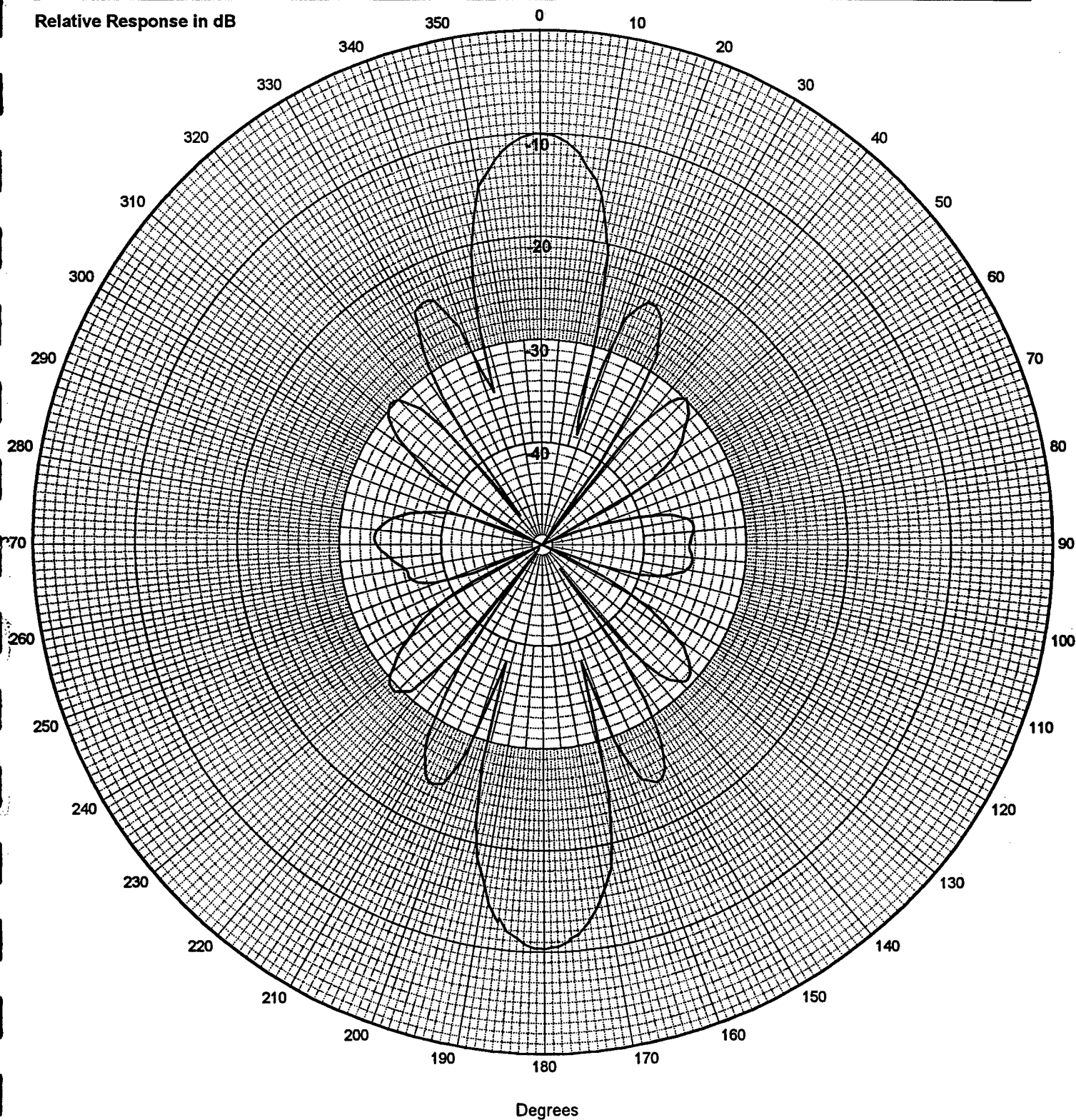
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-103  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

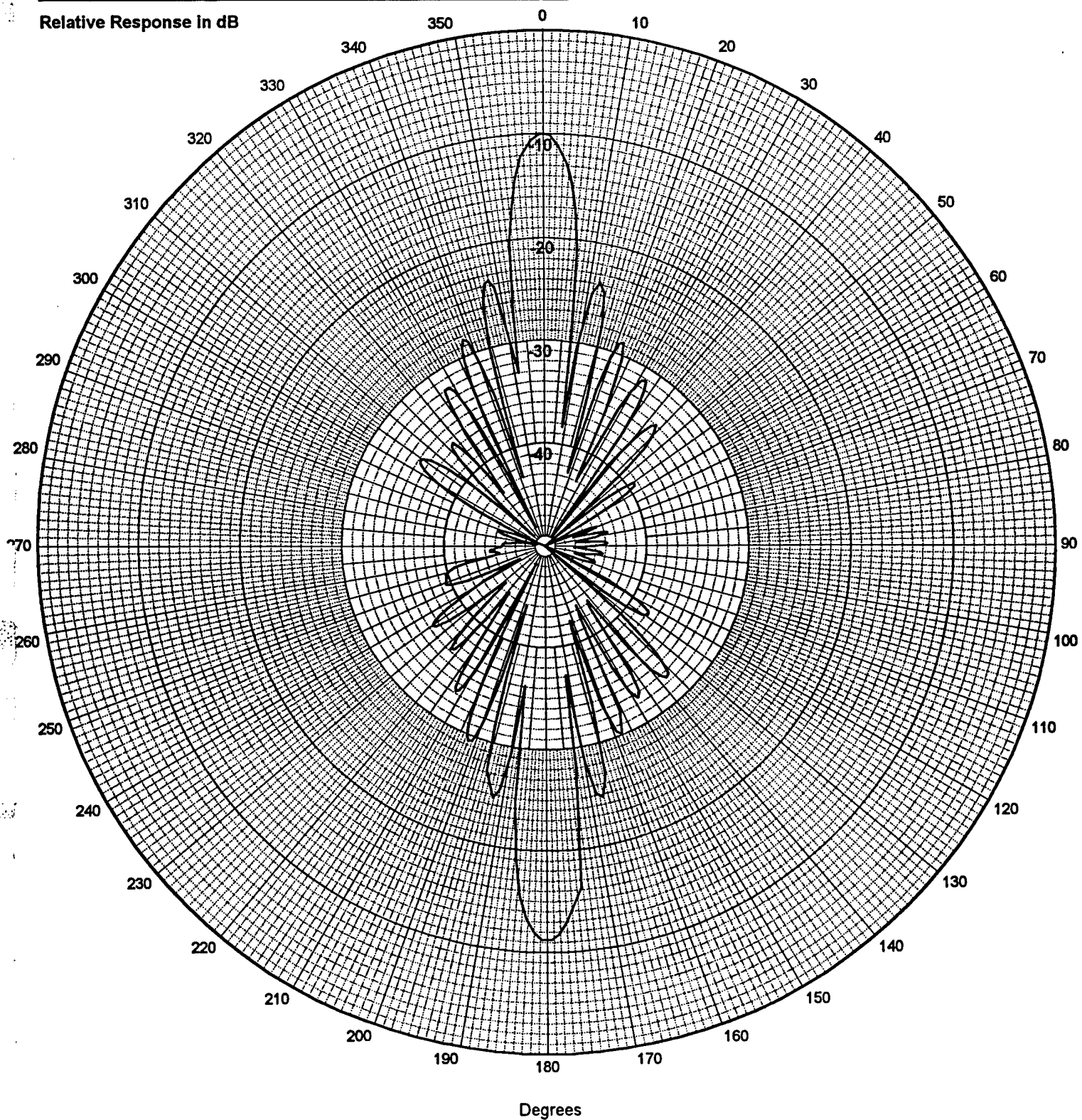
Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz



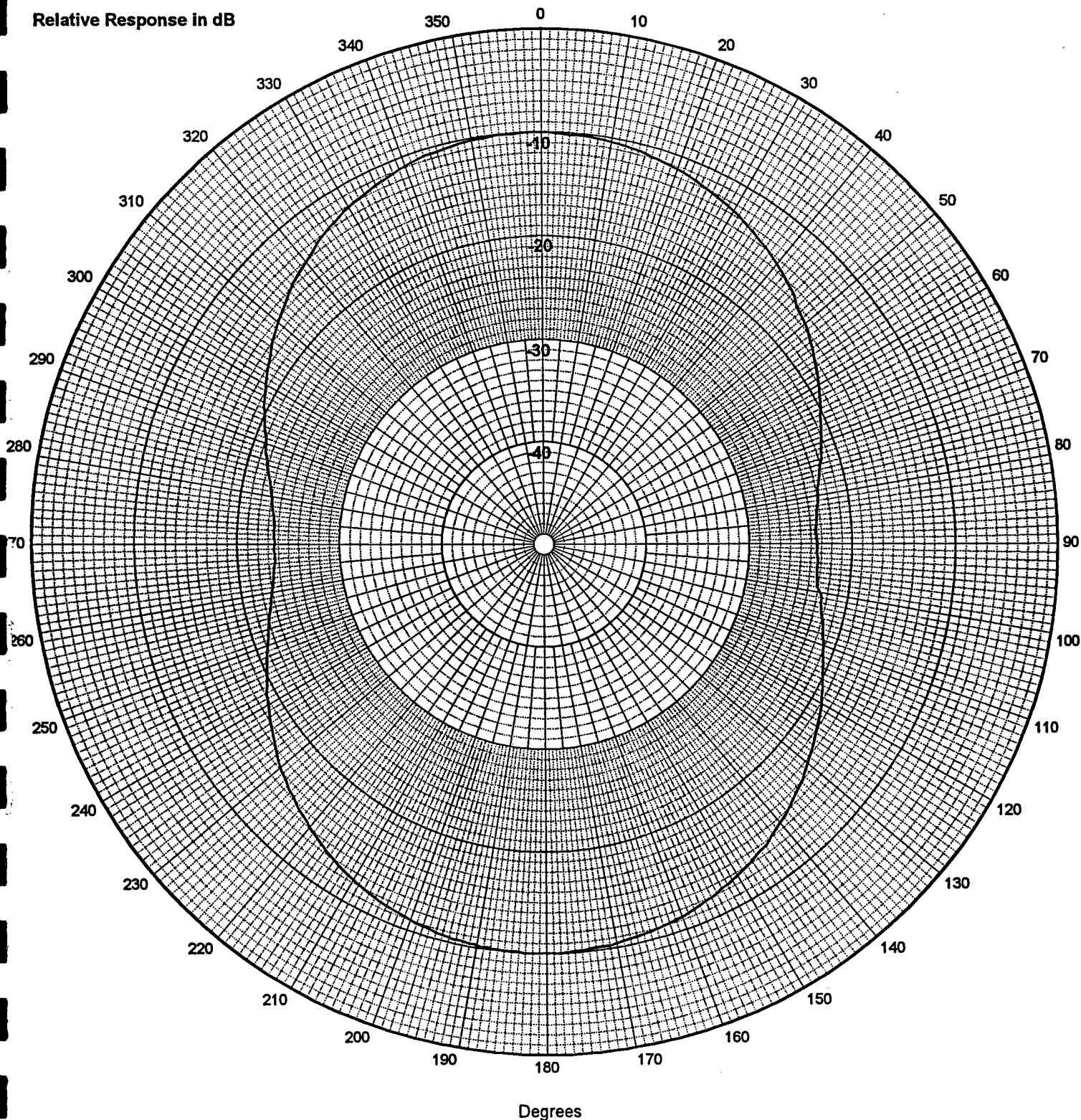
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-105  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

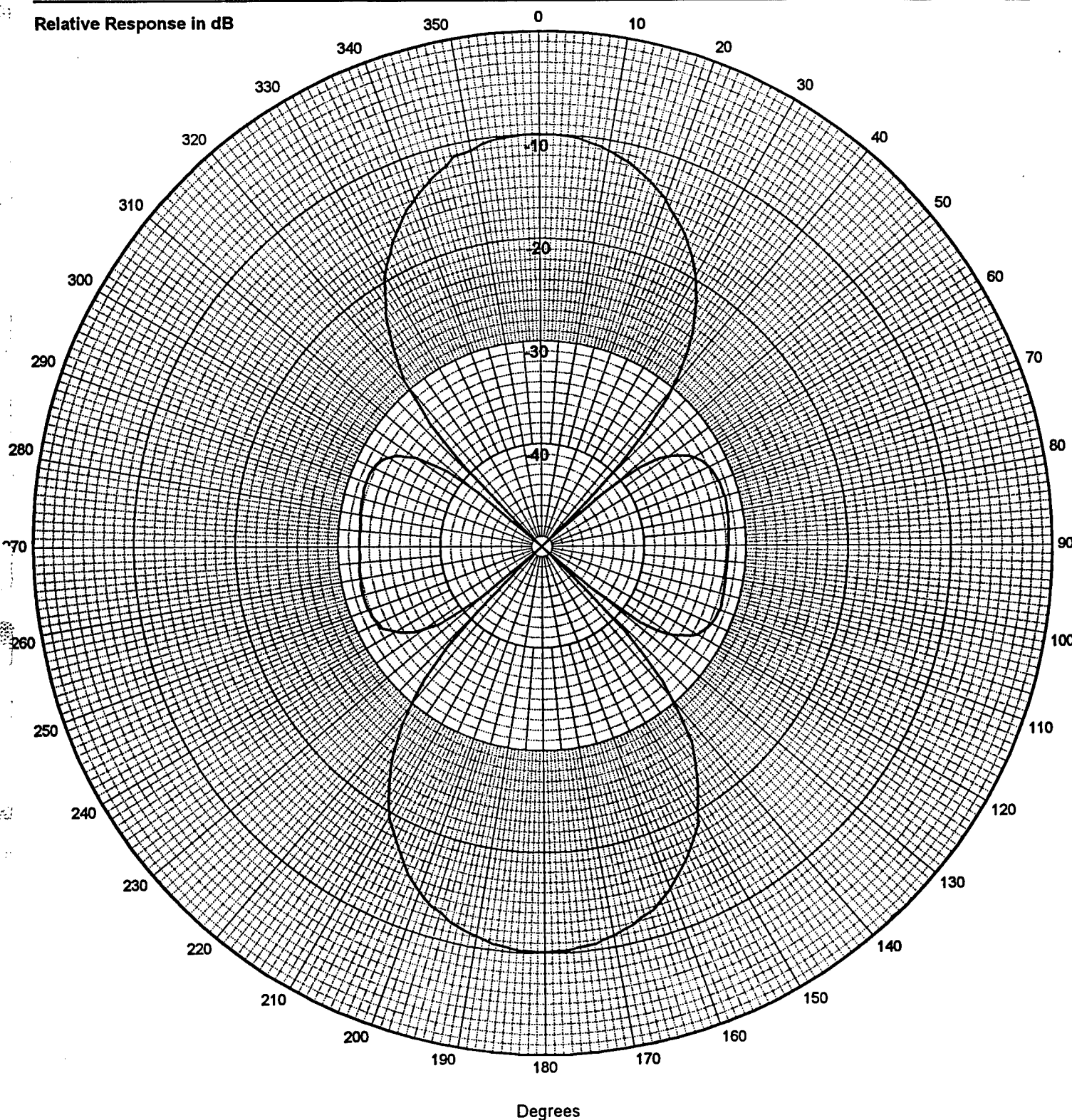
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB





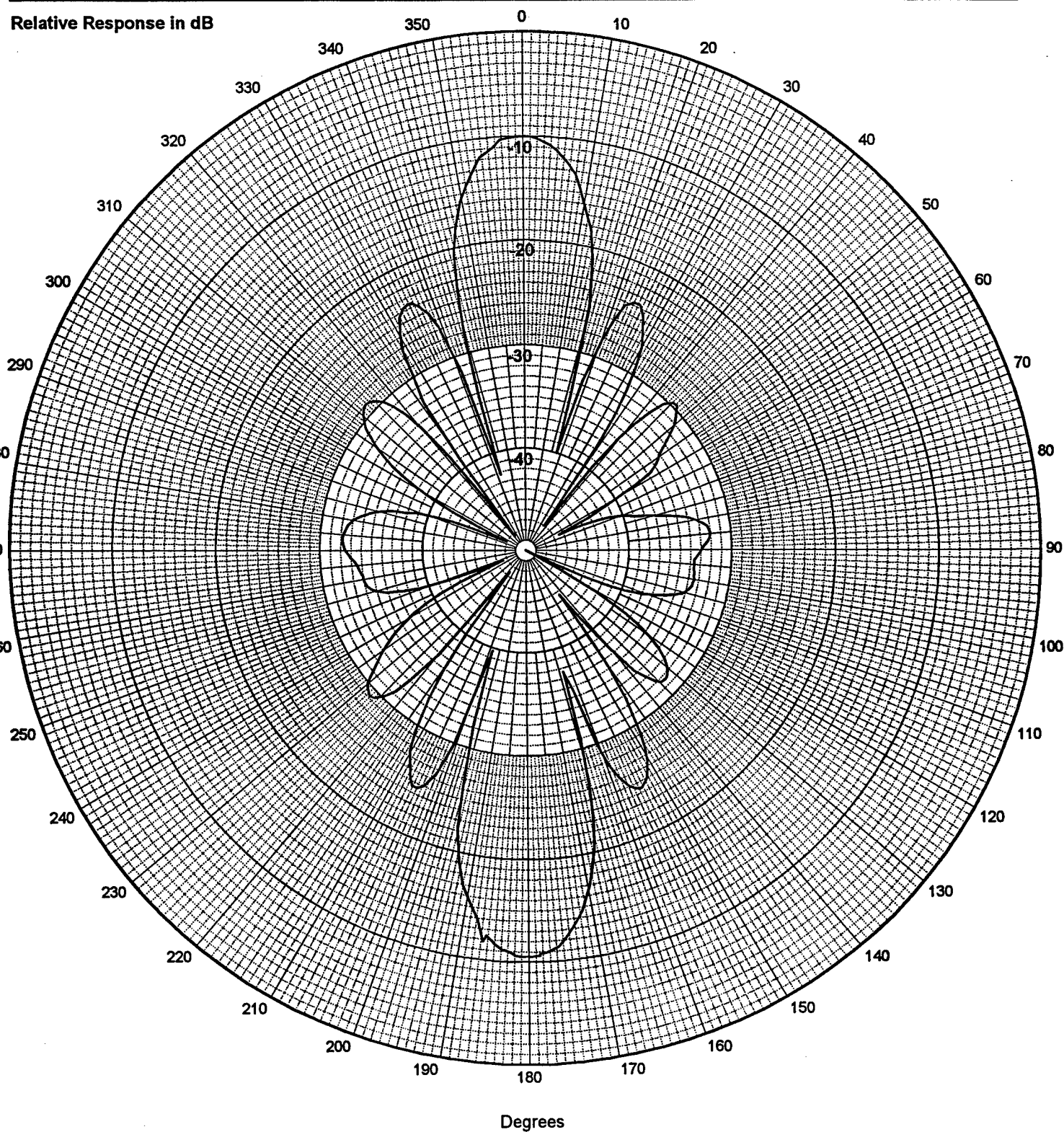
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0727-107  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-51

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

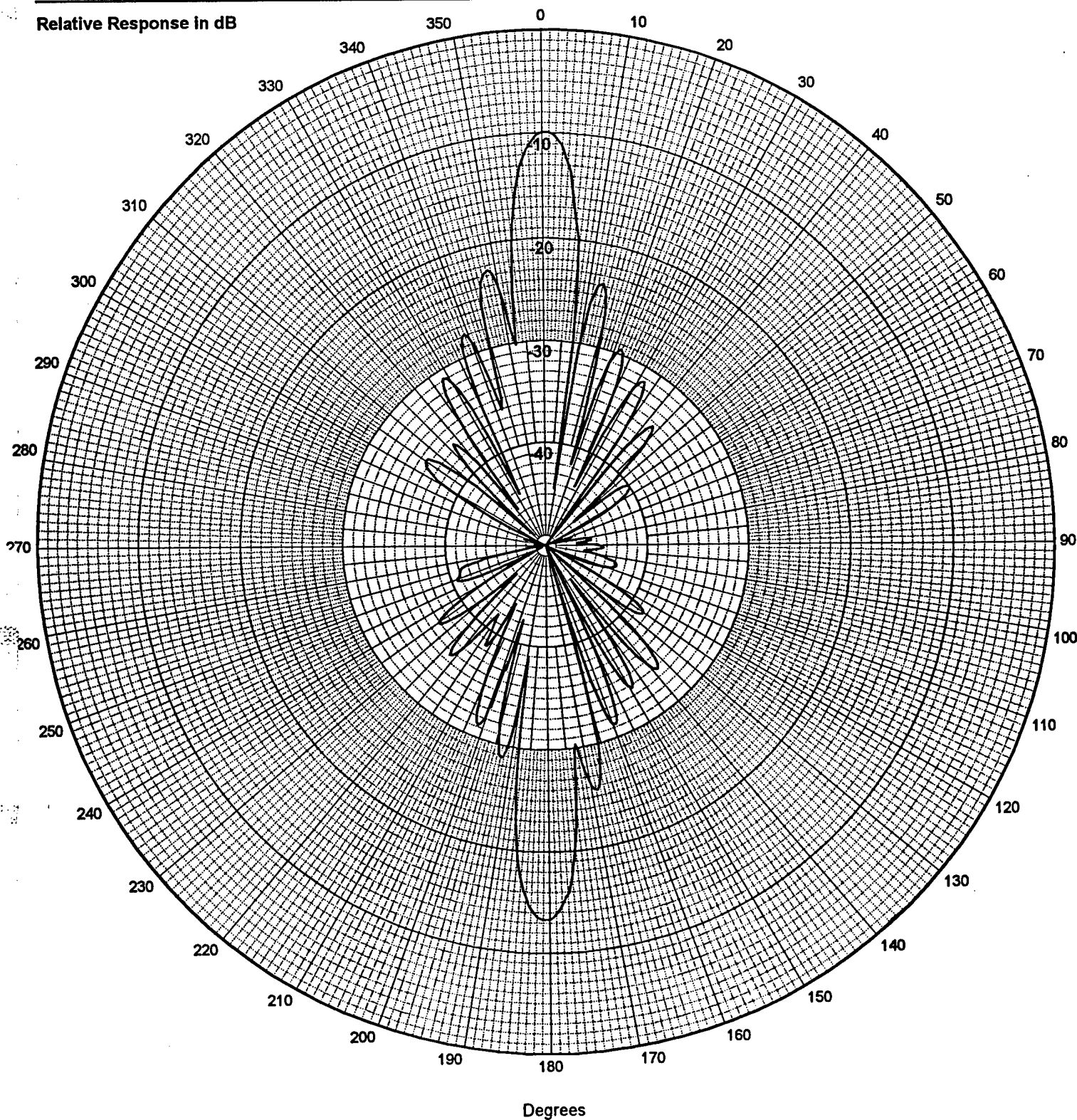
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB



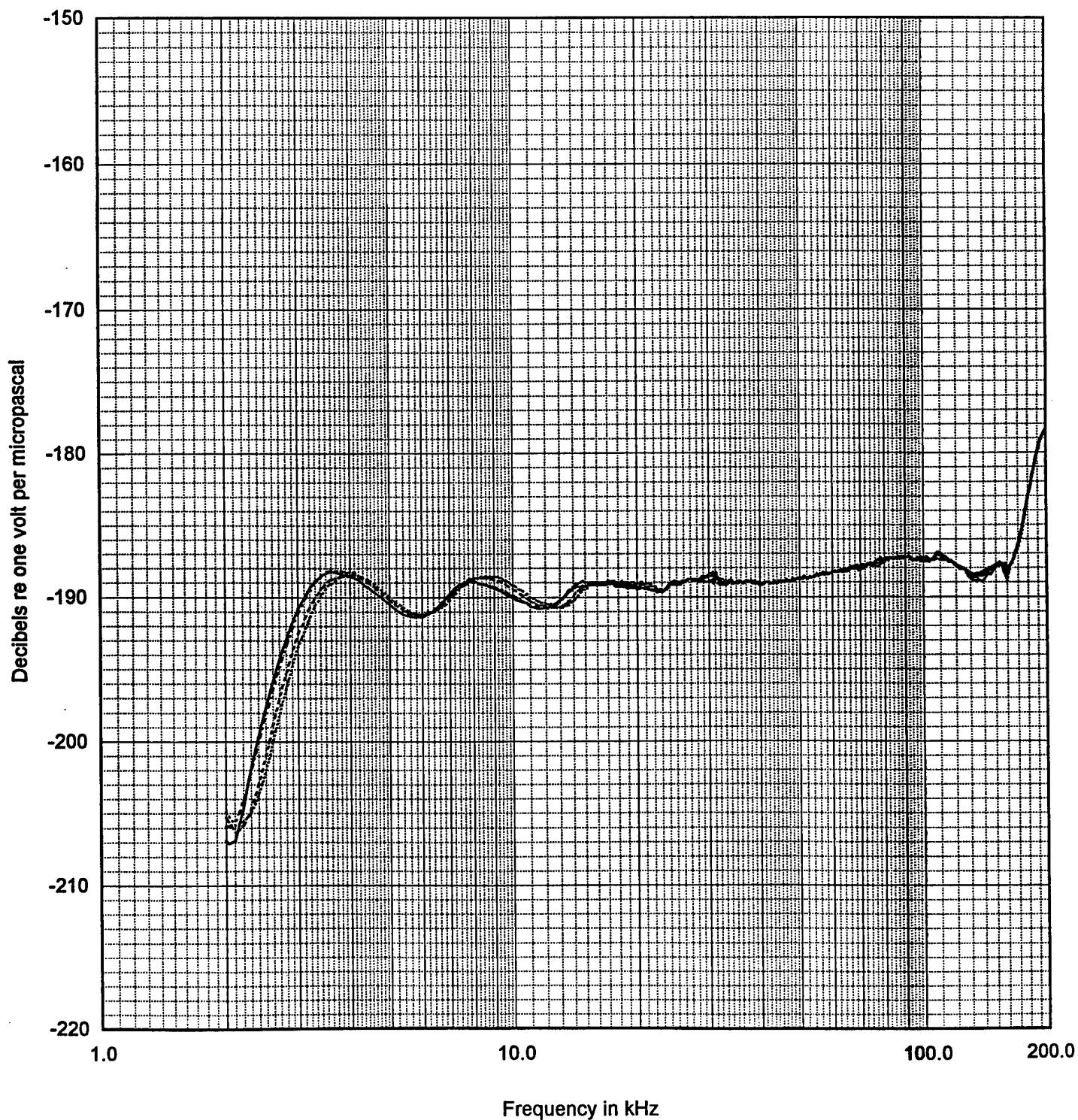
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-10P4

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 16 kPa ( 1.6 m) After Pressure



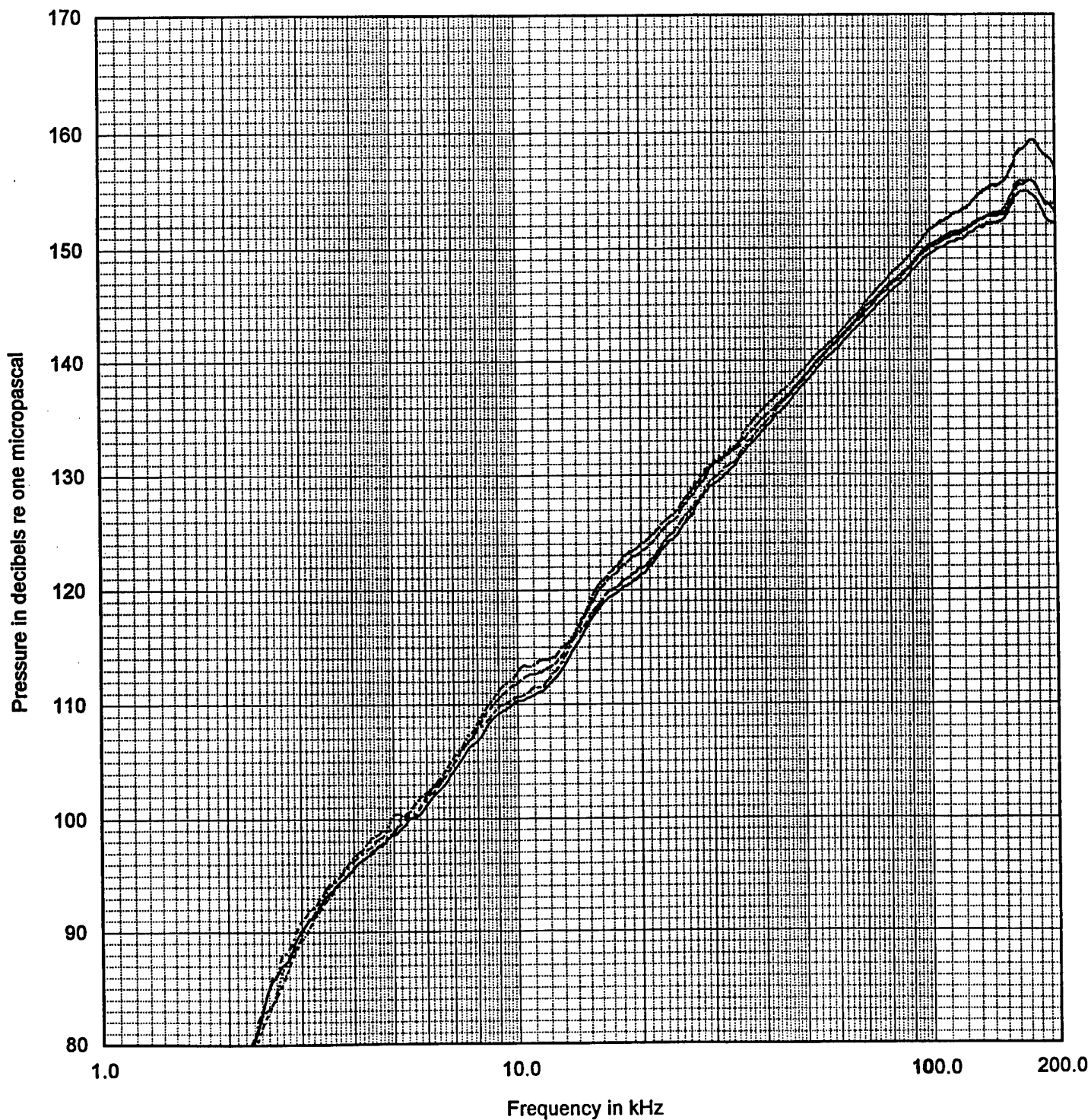
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-10P4

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

- 16 kPa ( 1.6 m) Before Pressure
- 3448 kPa ( 351.6 m)
- ..... 6895 kPa ( 703.1 m)
- 16 kPa ( 1.6 m) After Pressure



30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°40°  
320°50°  
310°60°  
300°70°  
290°80°  
280°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD/NO: 0727-111  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
Before Pressure  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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150°  
210°160°  
200°170°  
190°180°  
180°190°  
170°200°  
160°210°  
150°

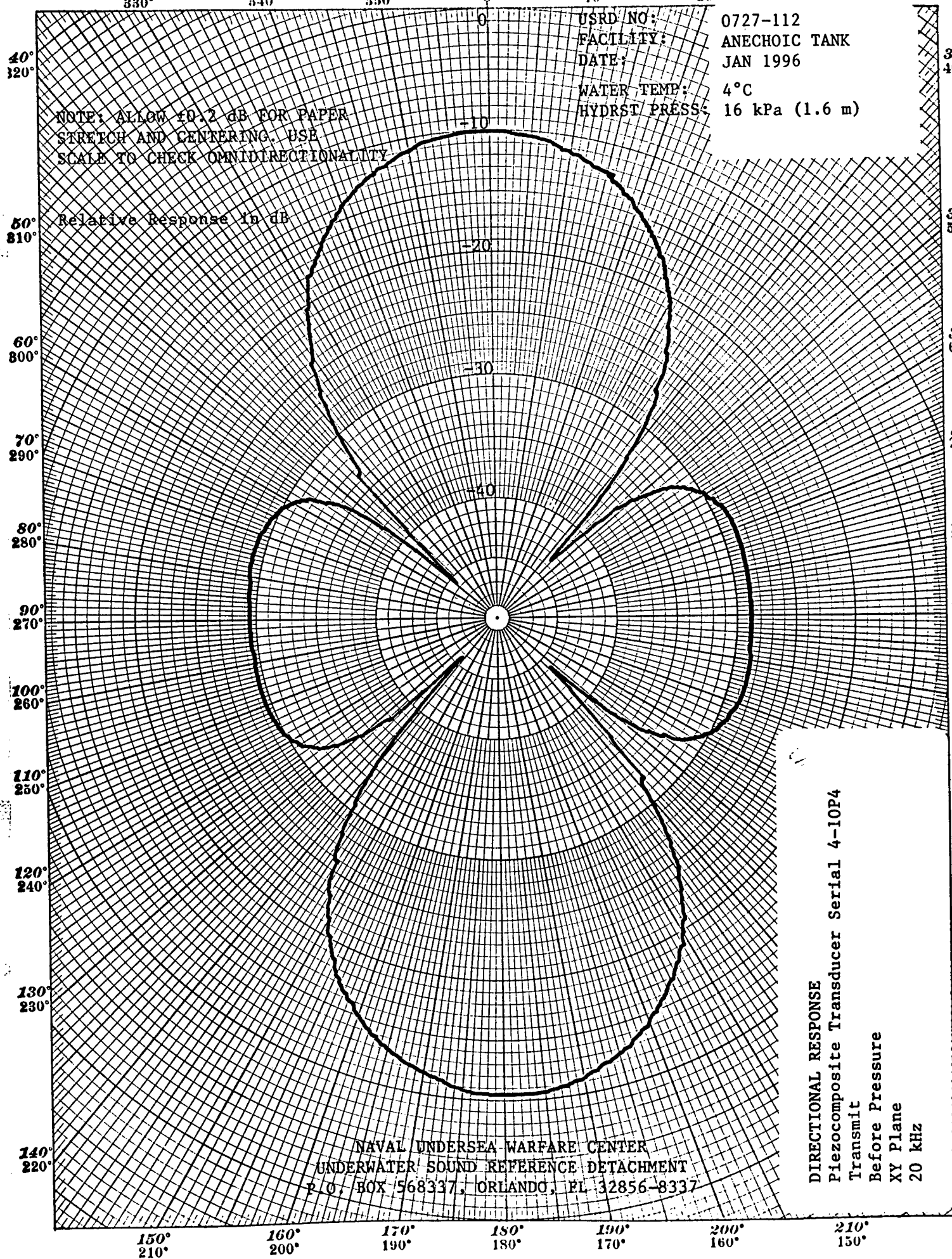


30° 20° 10° 0 350° 340° 330° 320° 310° 300° 290° 280° 270° 260° 250° 240° 230° 220° 210° 200° 190° 180° 170° 160° 150°

USRD NO: 0727-112  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
Before Pressure  
XY Plane  
20 kHz

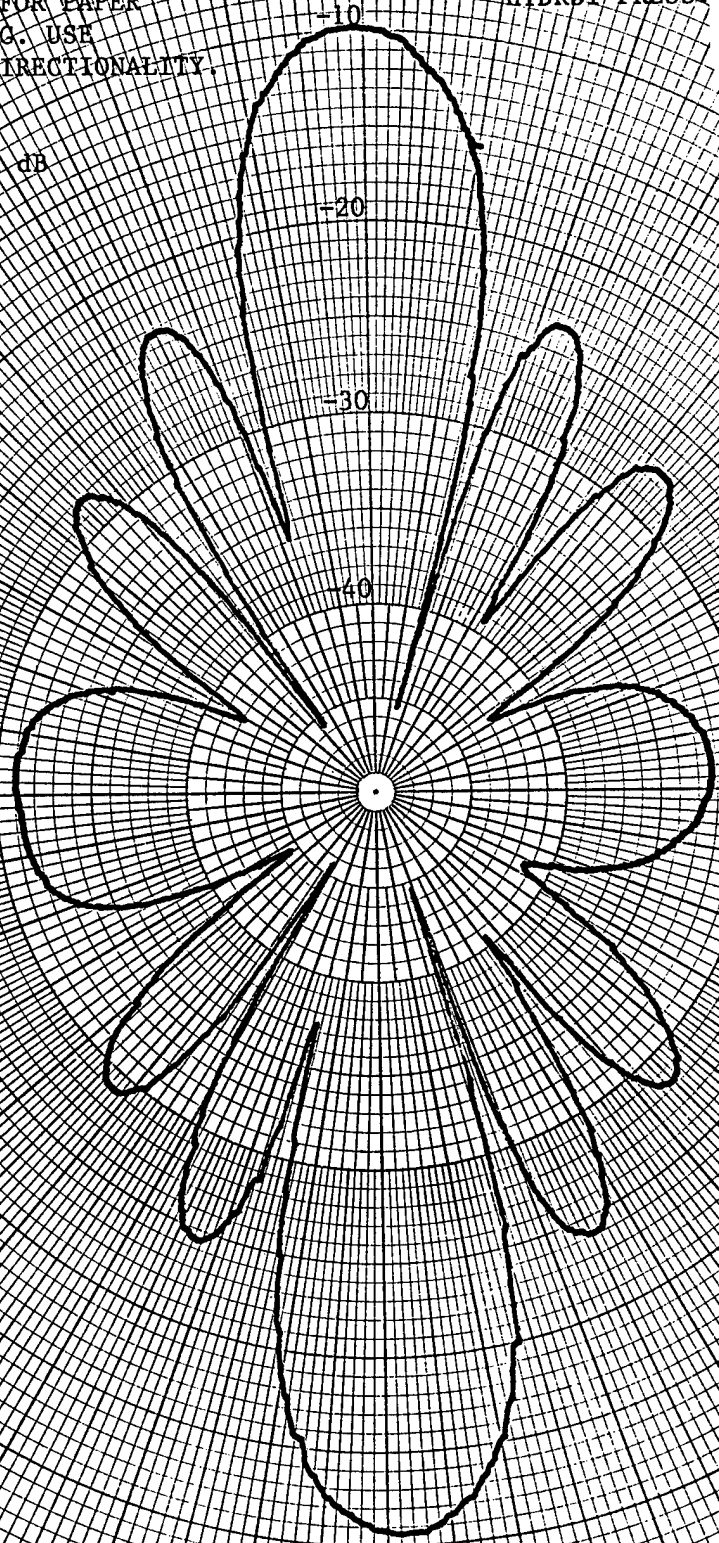


30° 20° 10° 0° 330° 340° 350° 10° 20° 30°

USRD NO: 0727-113  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
Before Pressure  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0°

10°  
300°

20°  
290°

30°  
280°

USRD NO: 0727-114  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

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UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
Before Pressure  
XY Plane  
100 kHz

30° 20° 10° 0 330° 340° 350° 10° 20° 330° 30°

USRD NO: 0727-115  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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30°  
330°

20°  
340°

10°  
350°

0°

10°  
30°

20°  
30°

30°  
30°

40°  
120°

50°  
810°

60°  
800°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

150°  
210°

160°  
200°

170°  
190°

180°  
180°

190°  
170°

200°  
160°

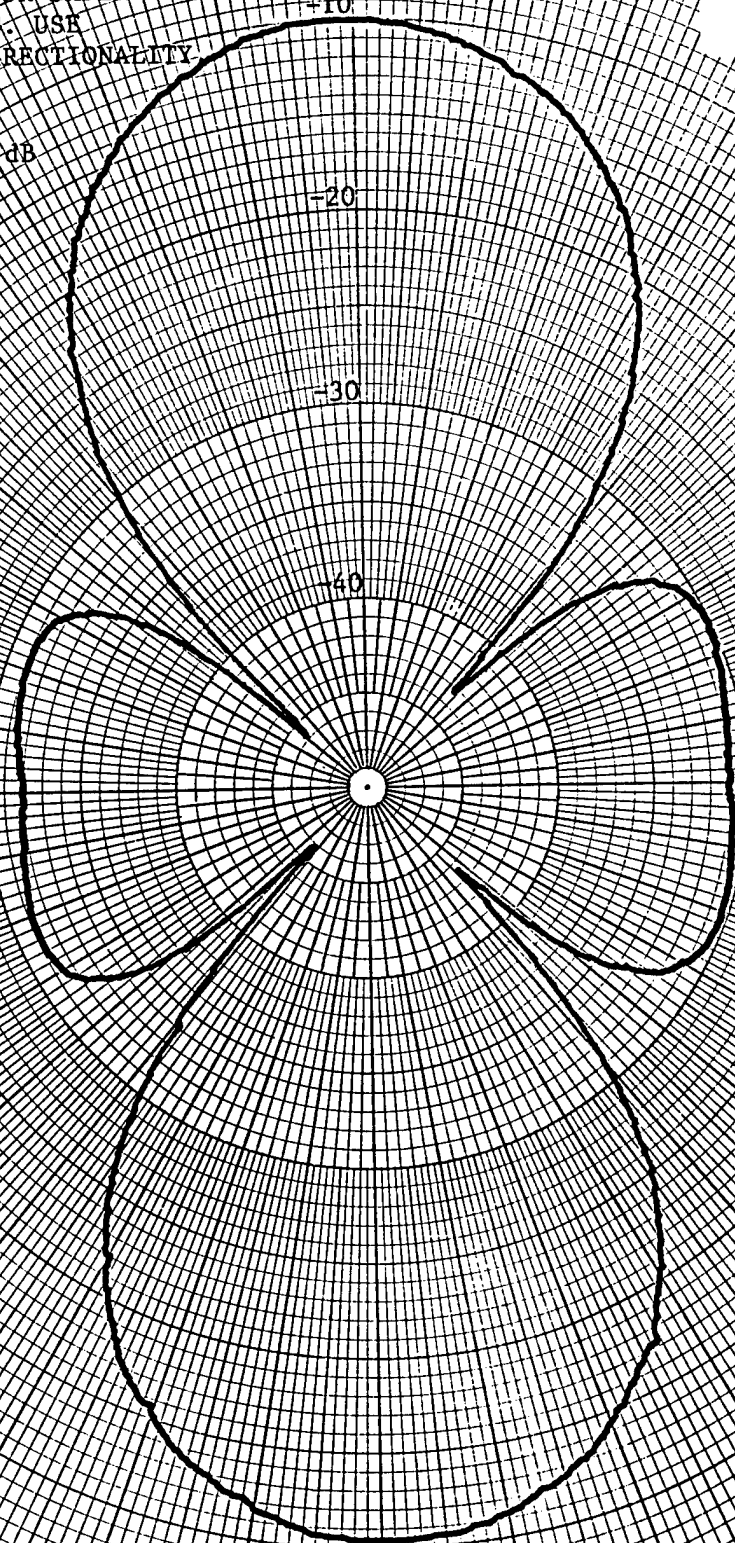
210°  
150°

USRD NO:  
FACILITY:  
DATE:

0727-116  
ANECHOIC TANK  
JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

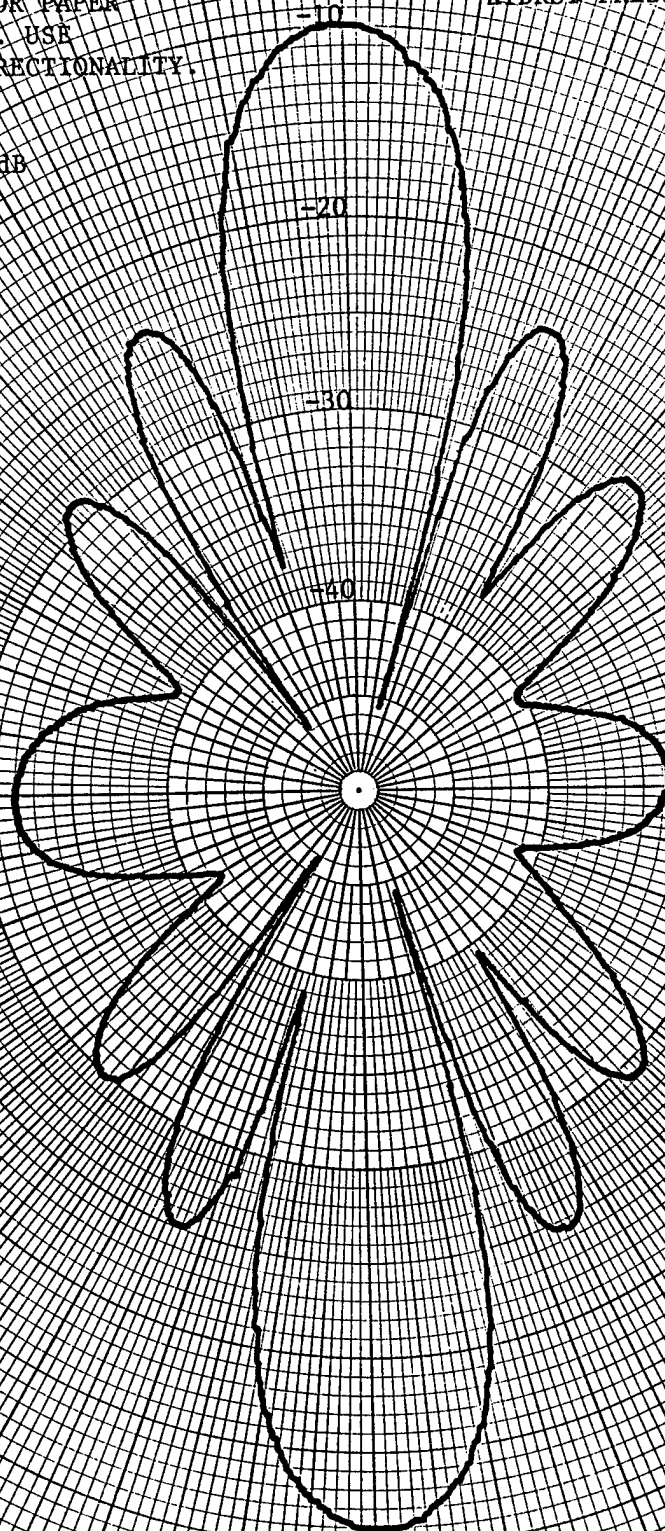
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
20 kHz

30° 20° 10° 0 330° 320° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-117  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
50 kHz



30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°40°  
320°50°  
310°60°  
300°70°  
290°80°  
280°90°  
270°100°  
260°110°  
250°120°  
240°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-118  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
100 kHz

00°  
330°

30°  
340°

60°  
330°

90°  
30°

120°  
30°

150°  
30°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

USRD NO: 0727-119  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

180°  
210°

150°  
200°

120°  
190°

90°  
180°

60°  
150°

30°  
120°

0°  
90°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

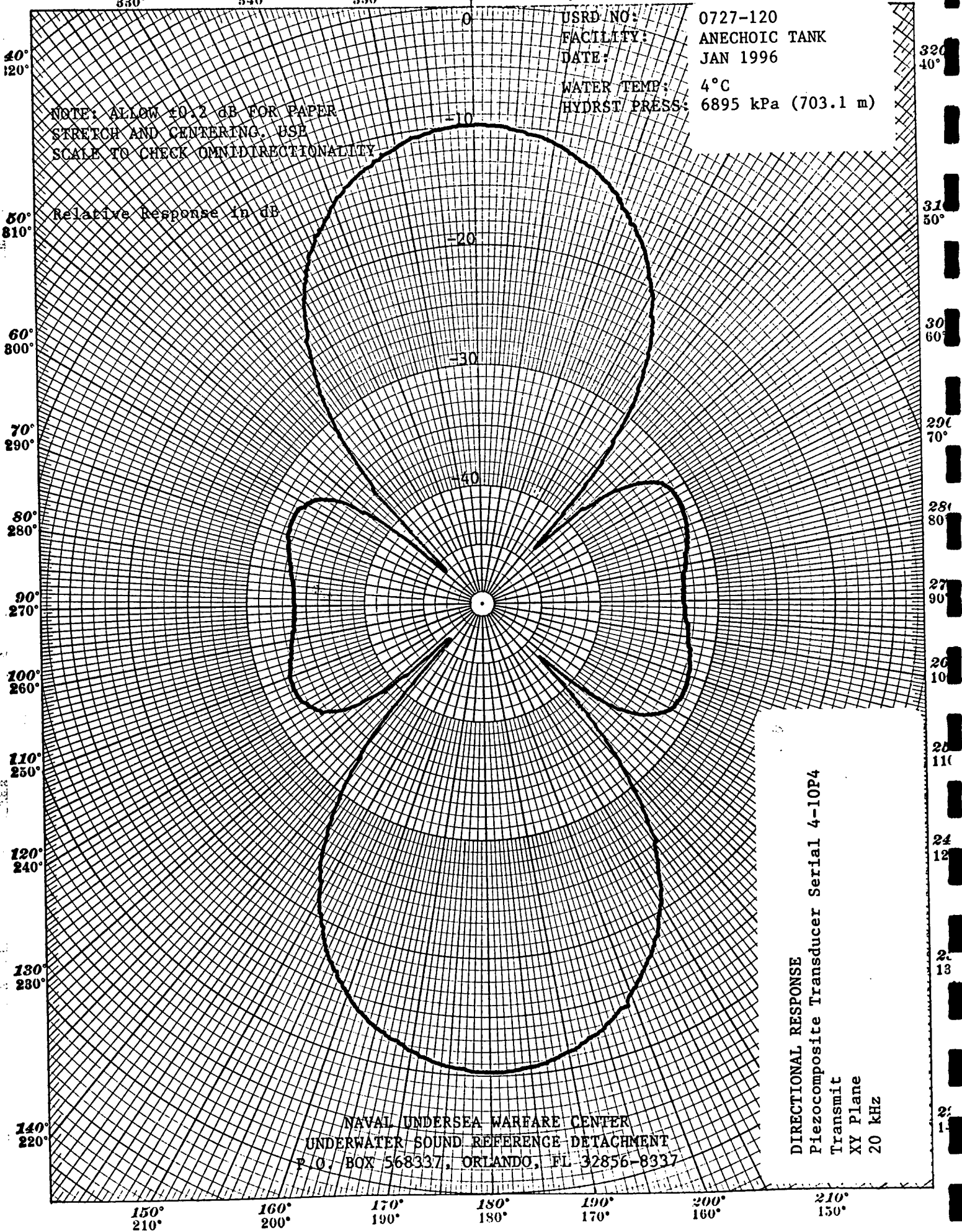
220°  
140°

30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-120  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
20 kHz



30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

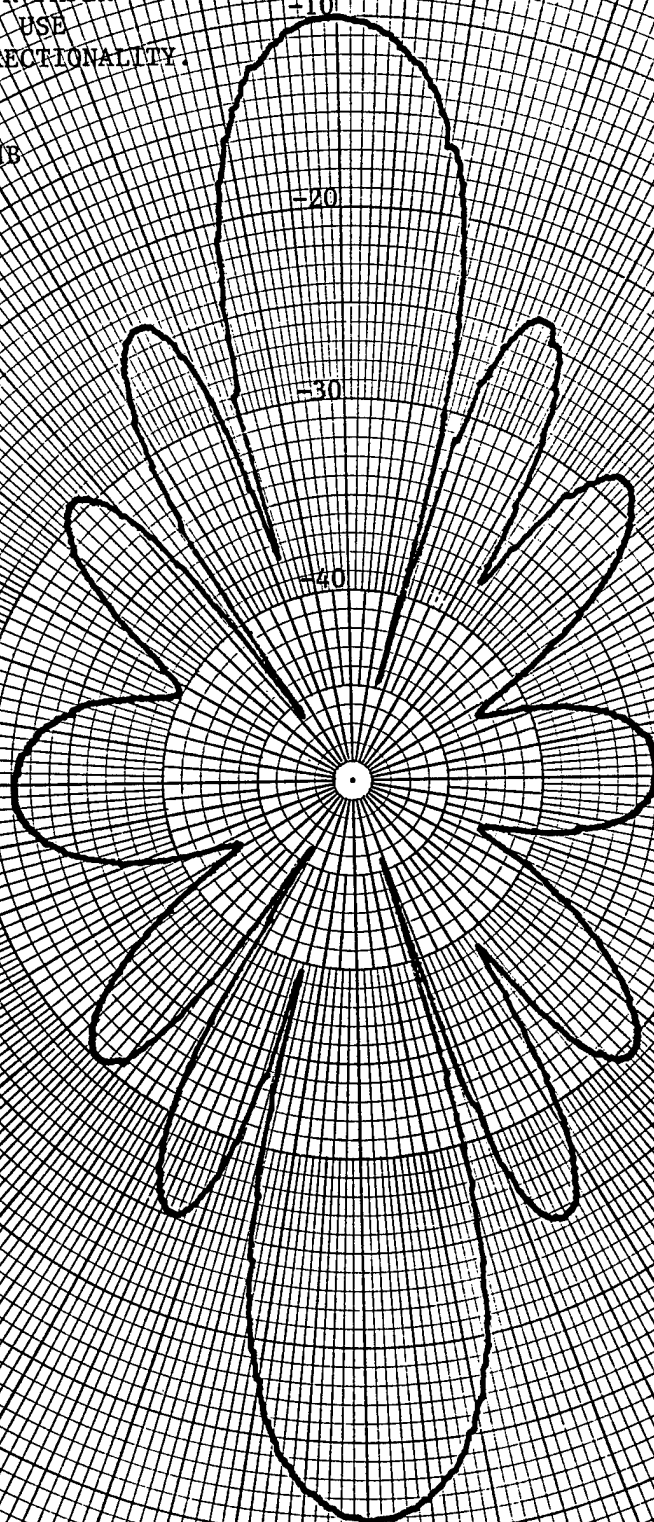
340°  
20°

330°  
30°

USRD NO: 0727-121  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

10°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO:

0727-122

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

6895 kPa (703.1 m)

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
XY Plane  
100 kHz



30° 20° 10° 0° 10° 20° 30°  
330° 340° 350° 360° 370° 380° 390°

USRD NO: 0727-123  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
After Pressure  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

150° 160° 170° 180° 190° 200° 210°  
210° 200° 190° 180° 170° 160° 150°

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

40°  
320°

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB

USRD NO: 0727-124  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
After Pressure  
XY Plane  
20 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

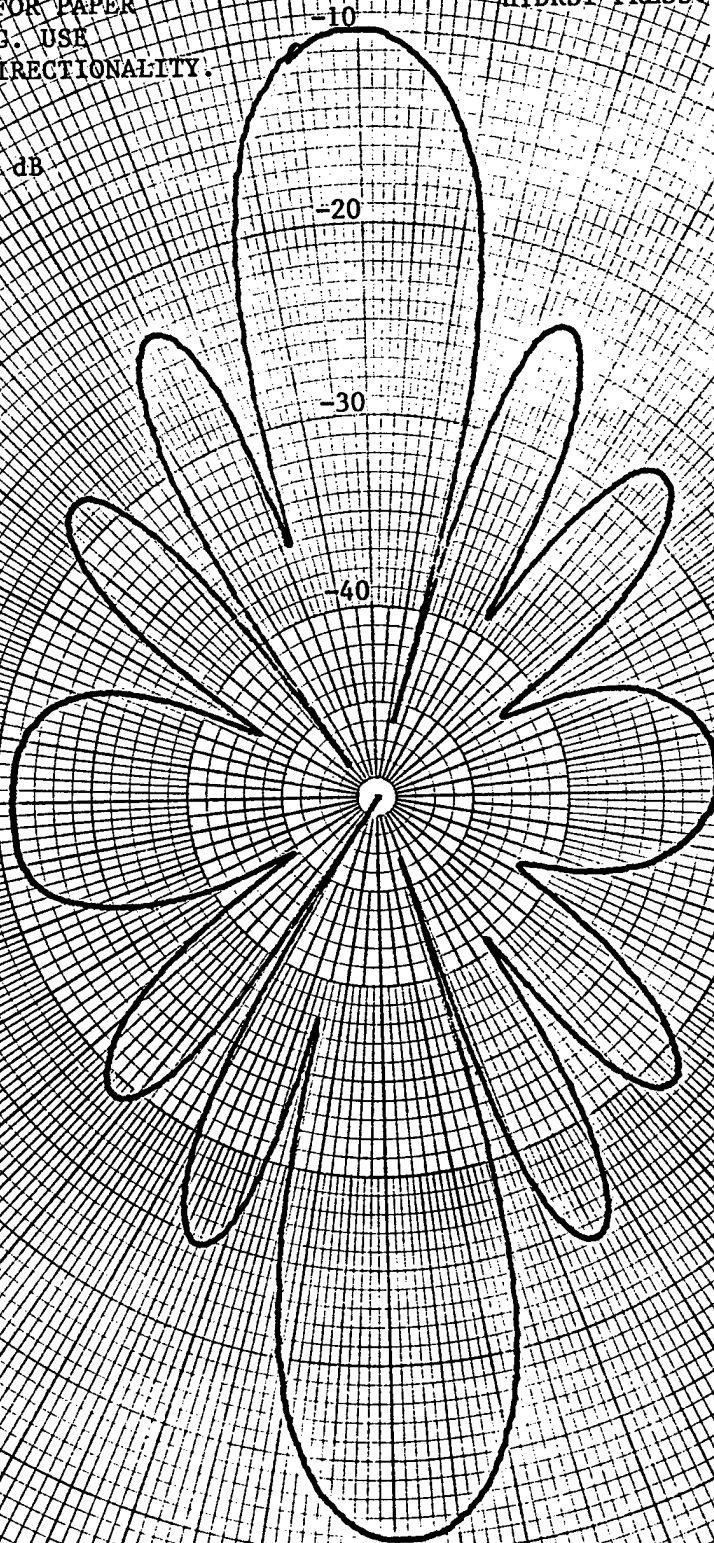
340°  
20°

330°  
30°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

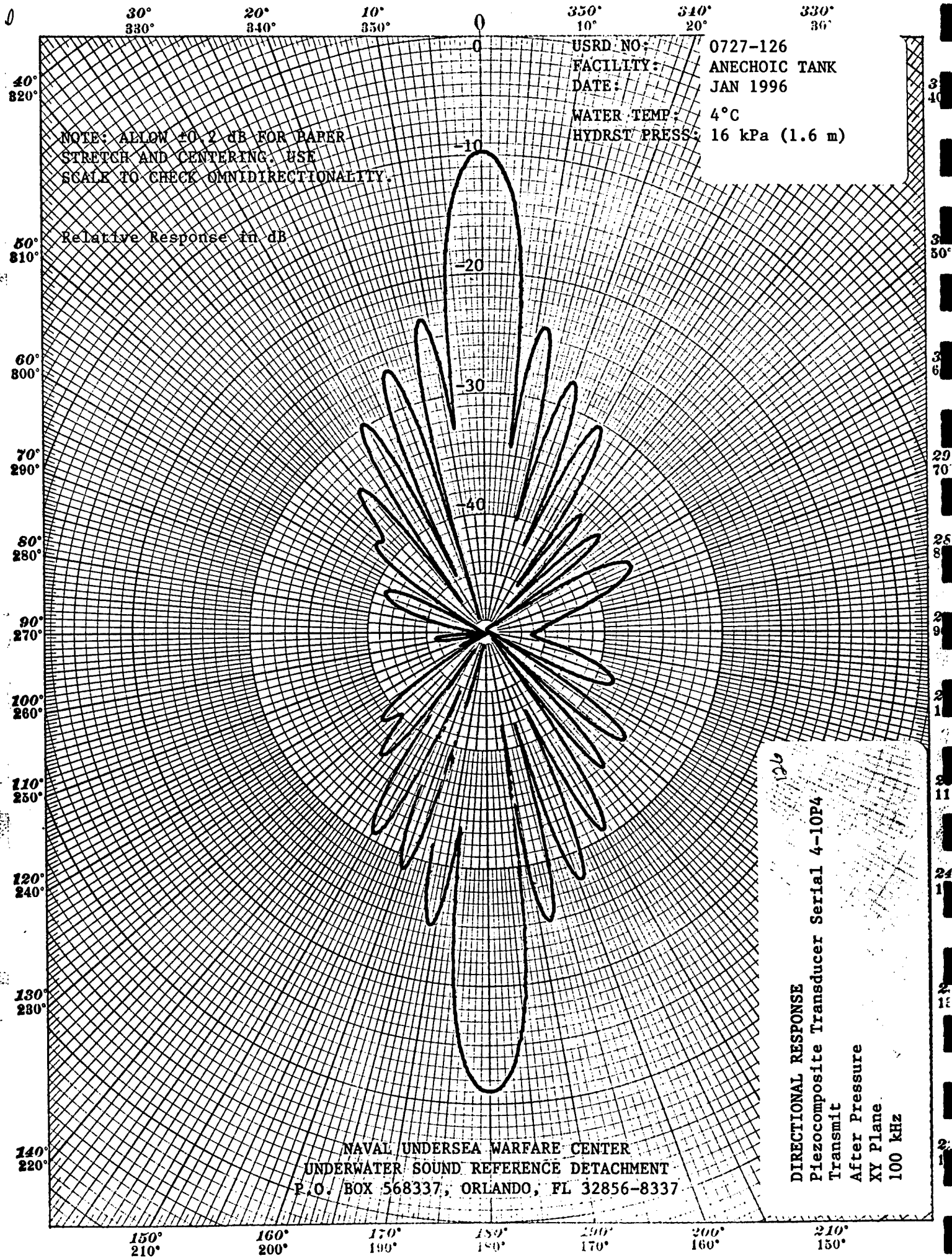
USRD NO: 0727-125  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
After Pressure  
XY Plane  
50 kHz





NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER STRETCH AND CENTERING. USE SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-126  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

126  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-10P4  
Transmit  
After Pressure  
XY Plane  
100 kHz

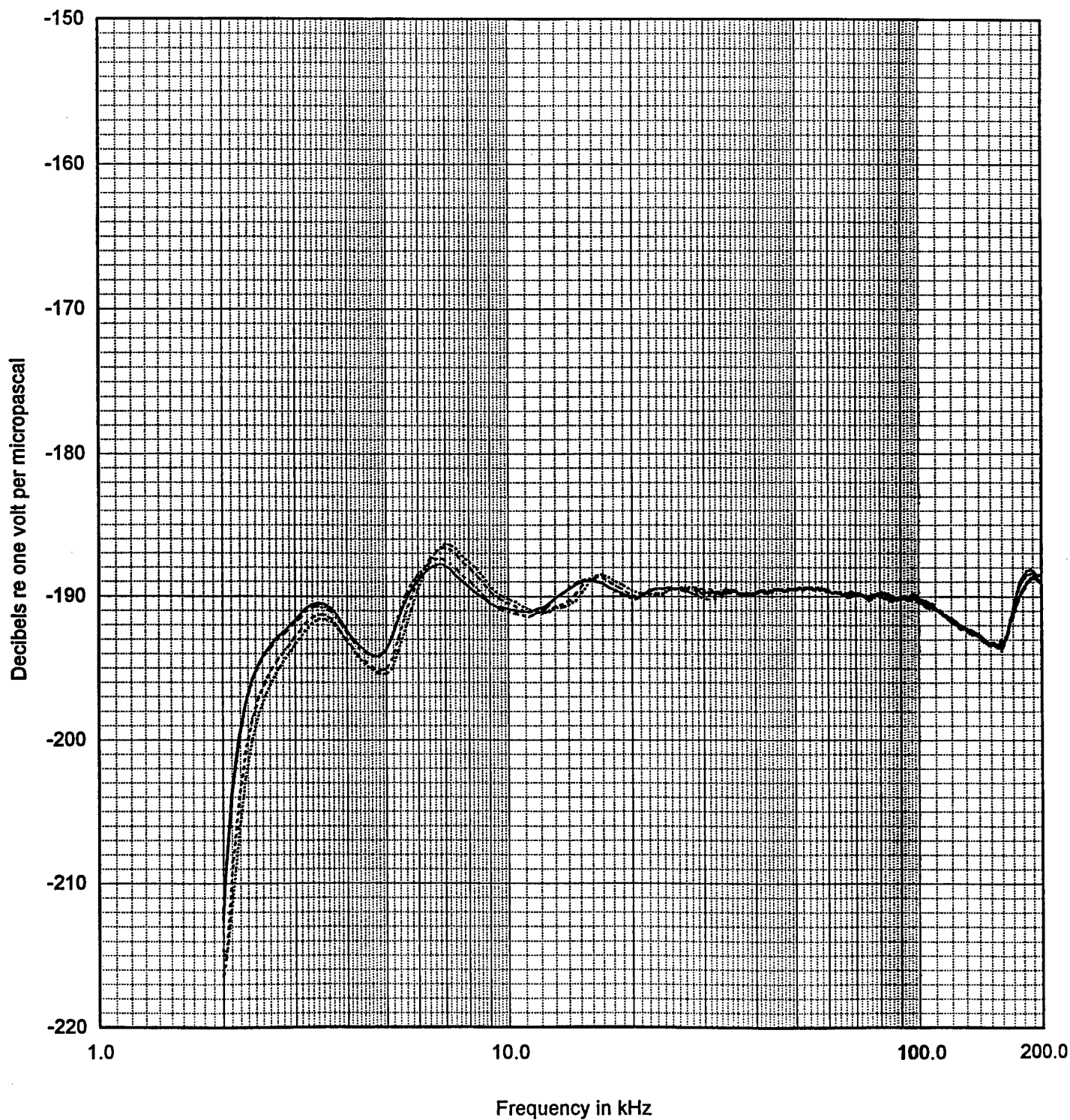
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-10P4

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

- 16 kPa ( 1.6 m) Before Pressure
- - - - - 3448 kPa ( 351.6 m)
- ..... 6895 kPa ( 703.1 m)
- - - - - 16 kPa ( 1.6 m) After Pressure





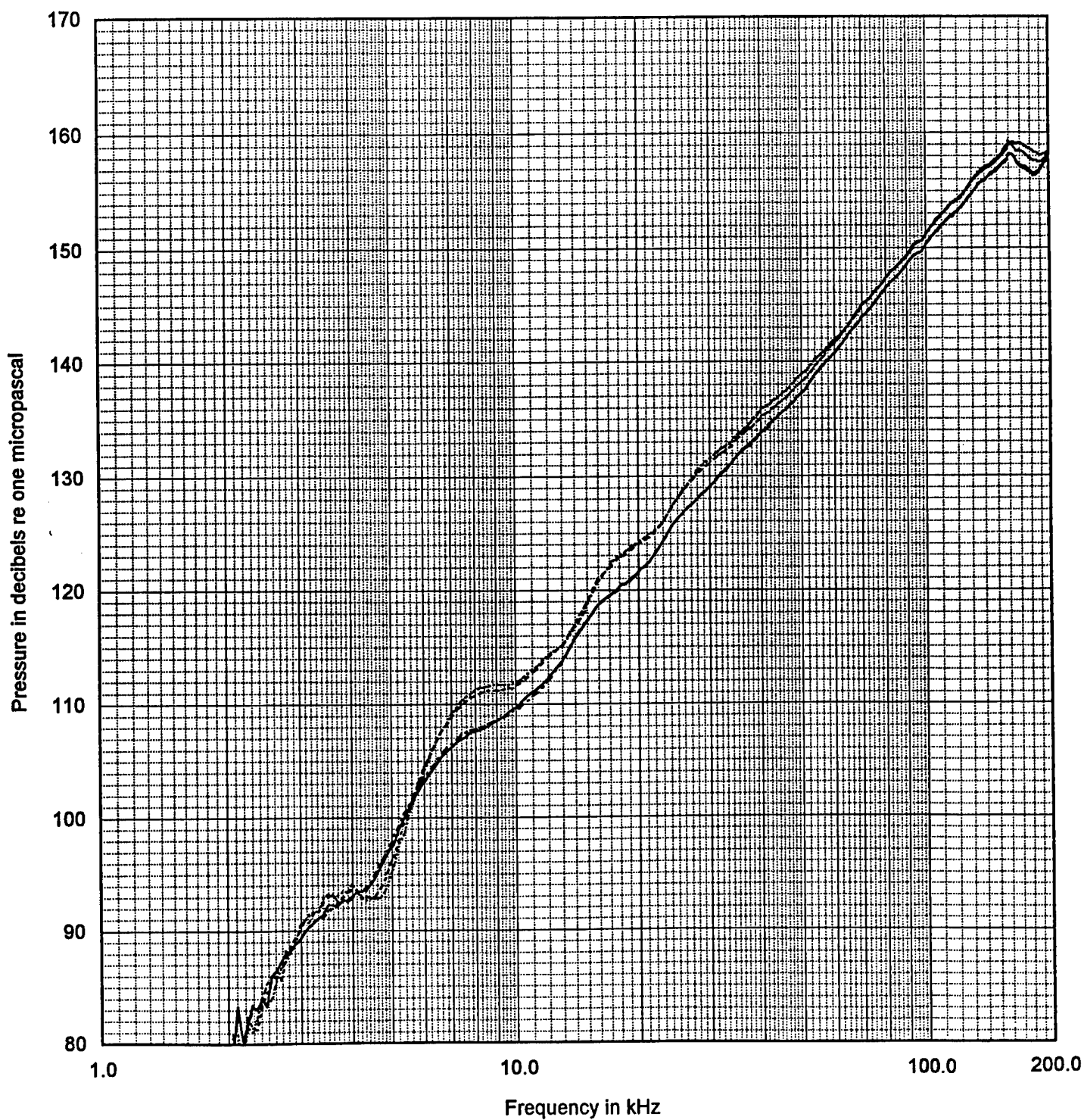
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-10P4

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-129  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

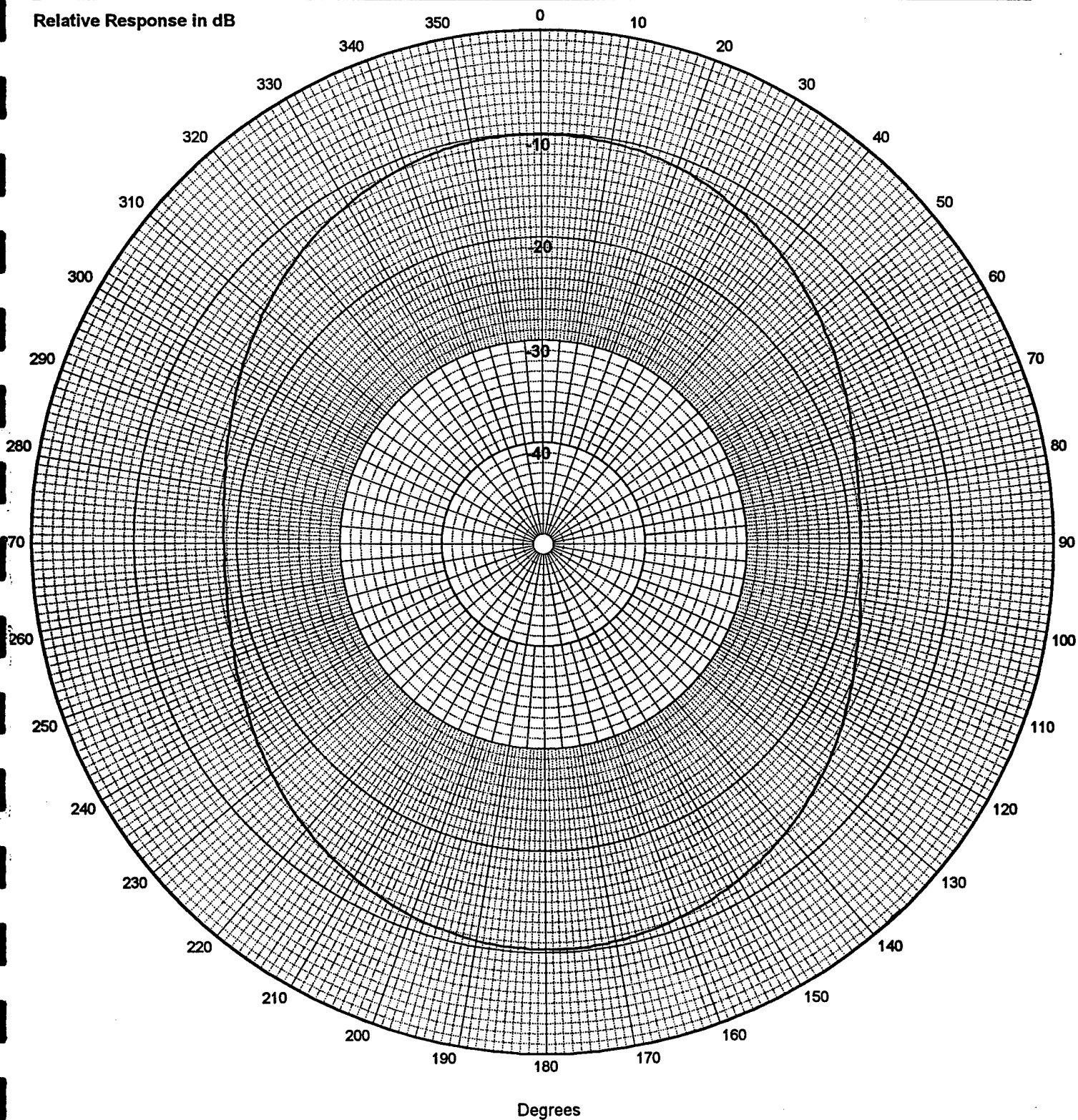
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

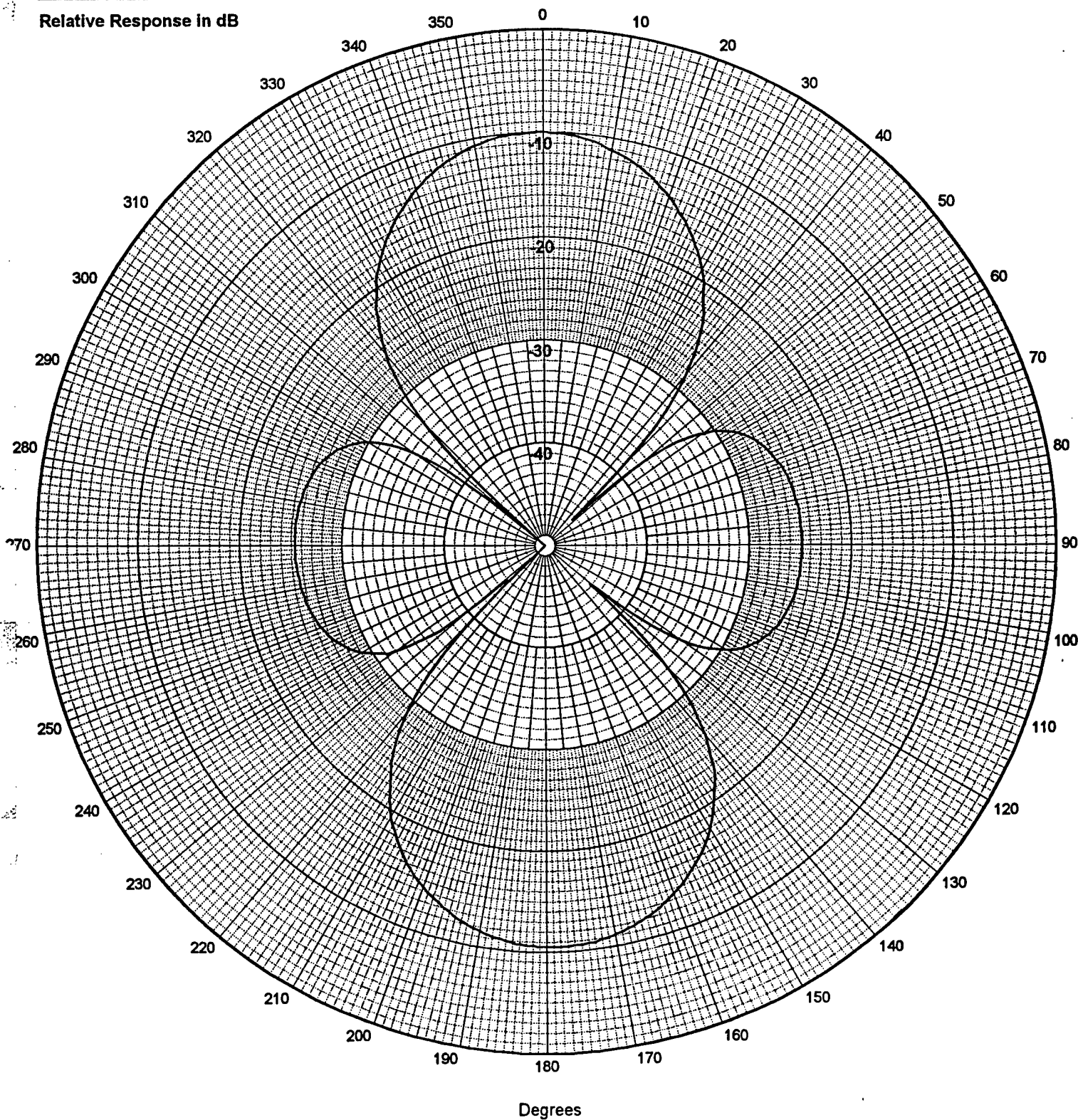
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

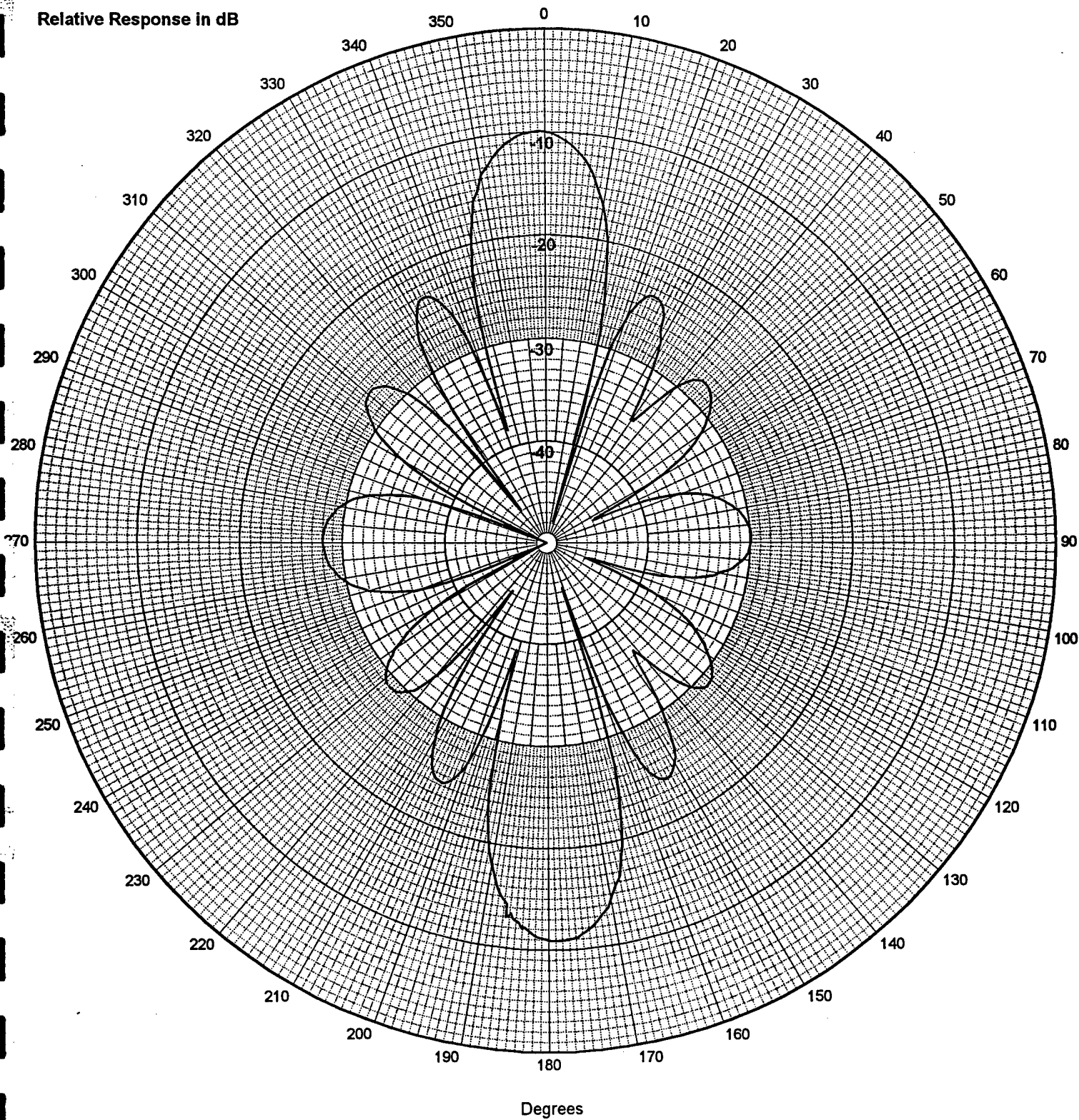
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB





NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-132  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

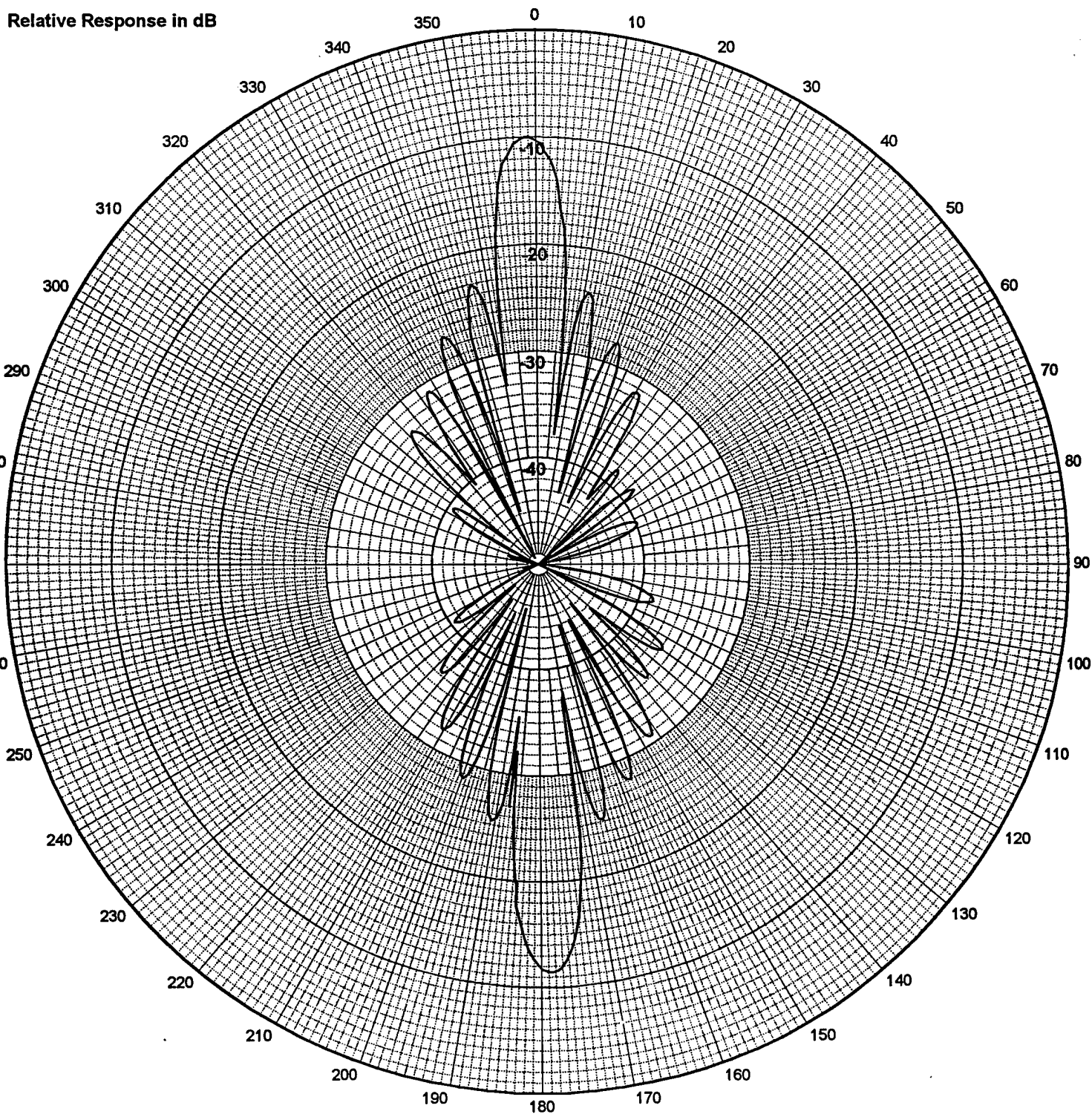
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB

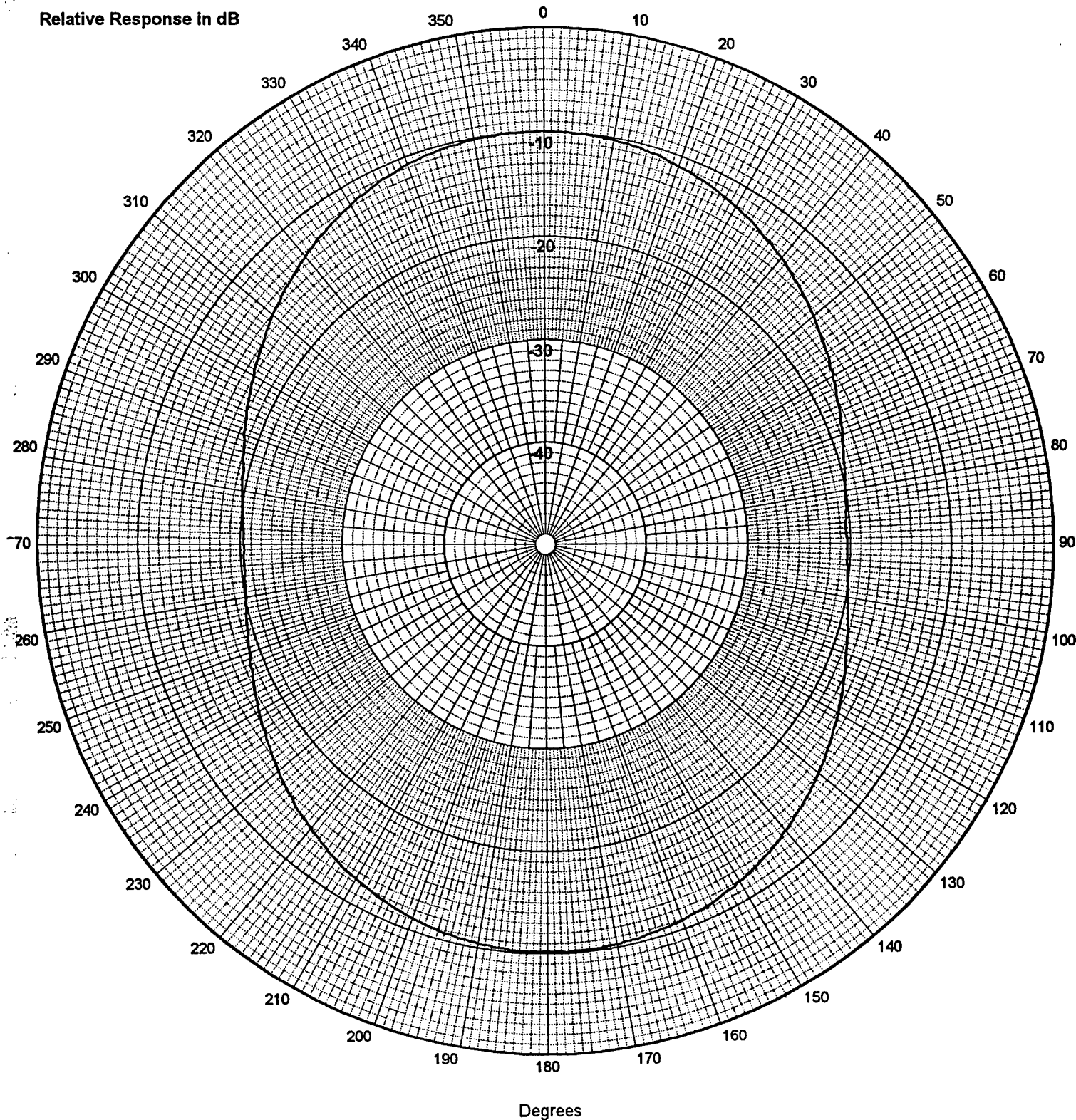


Degrees



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz



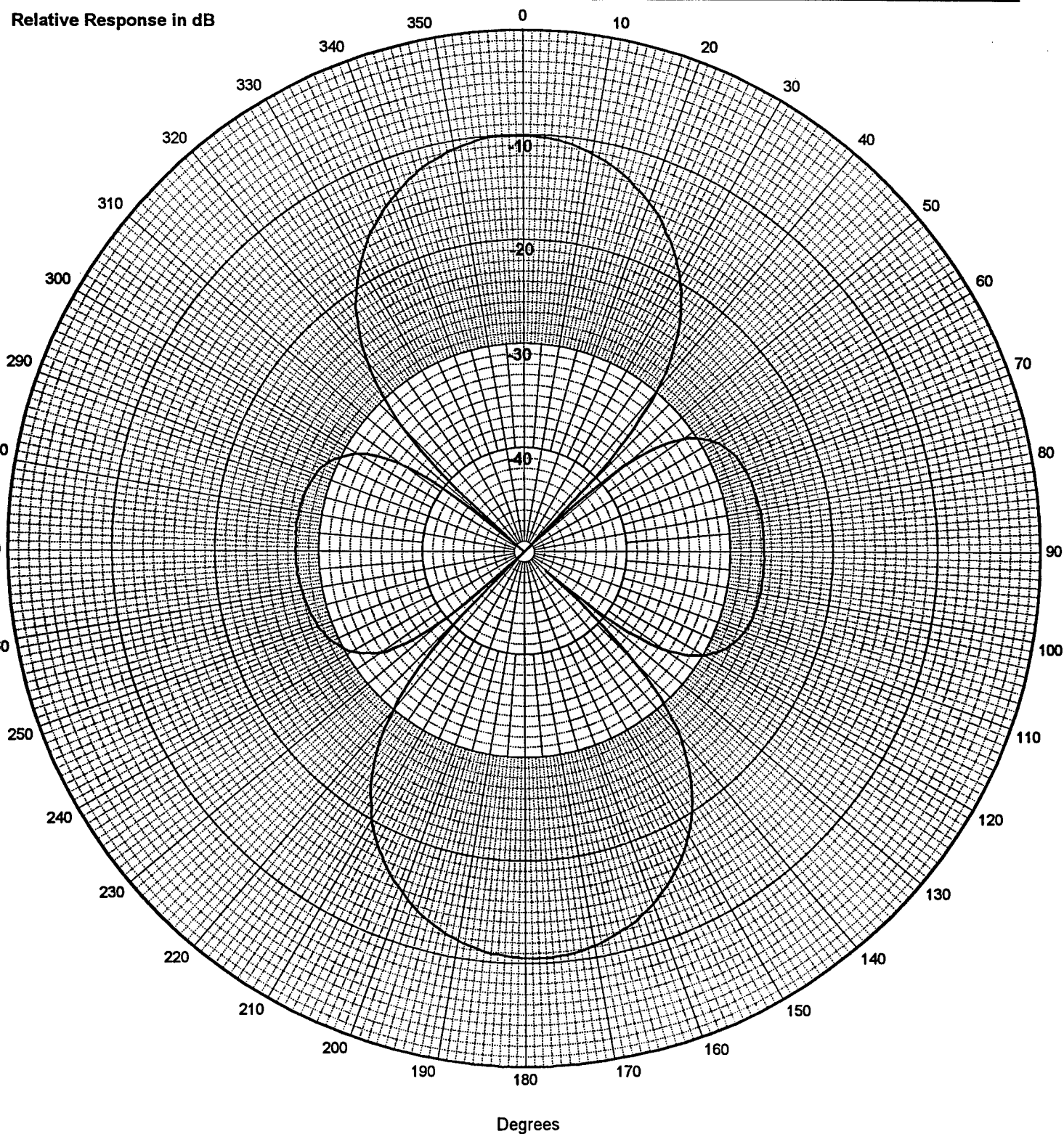
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-134  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

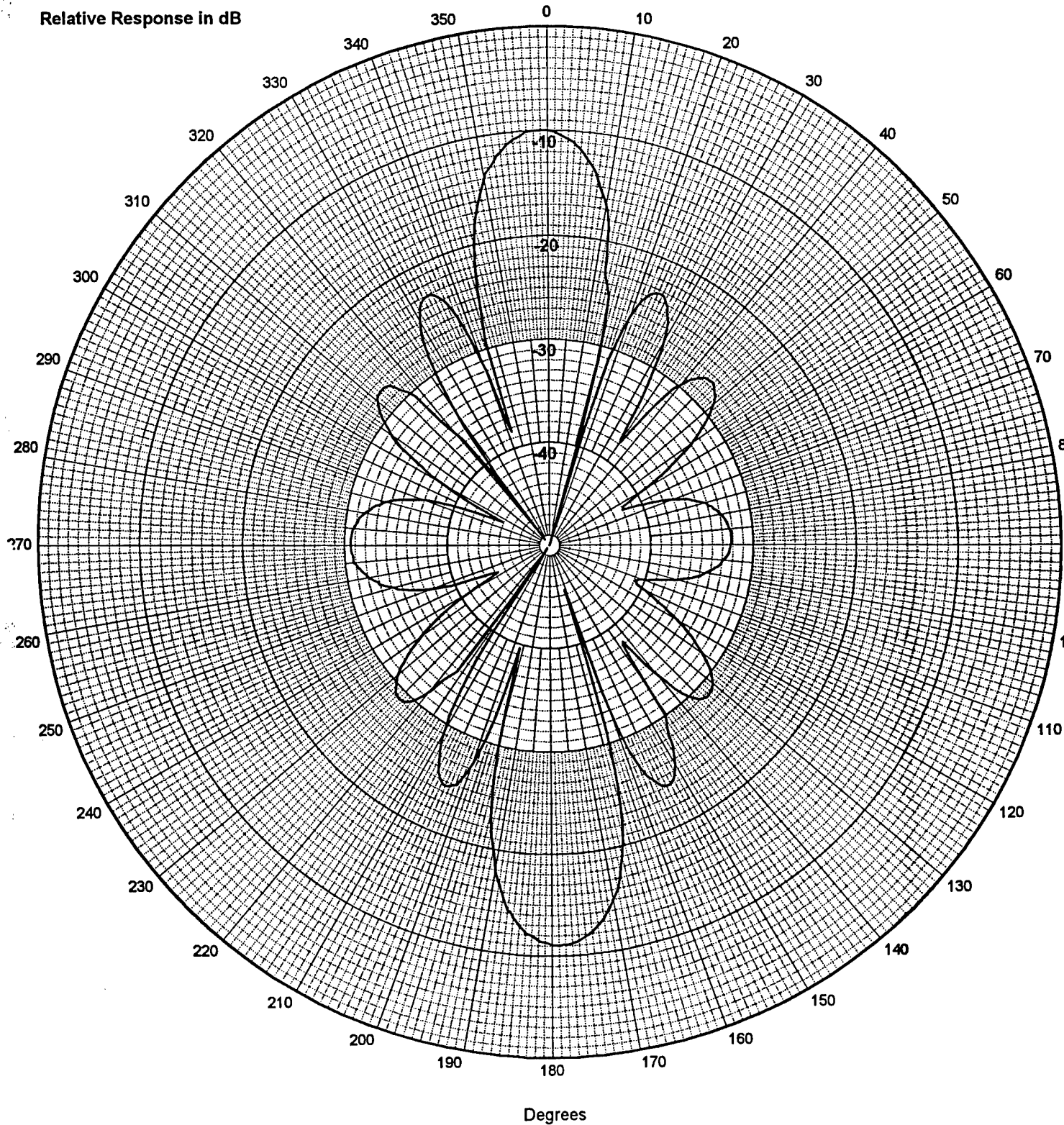
Piezocomposite Transducer Serial 4-10P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz



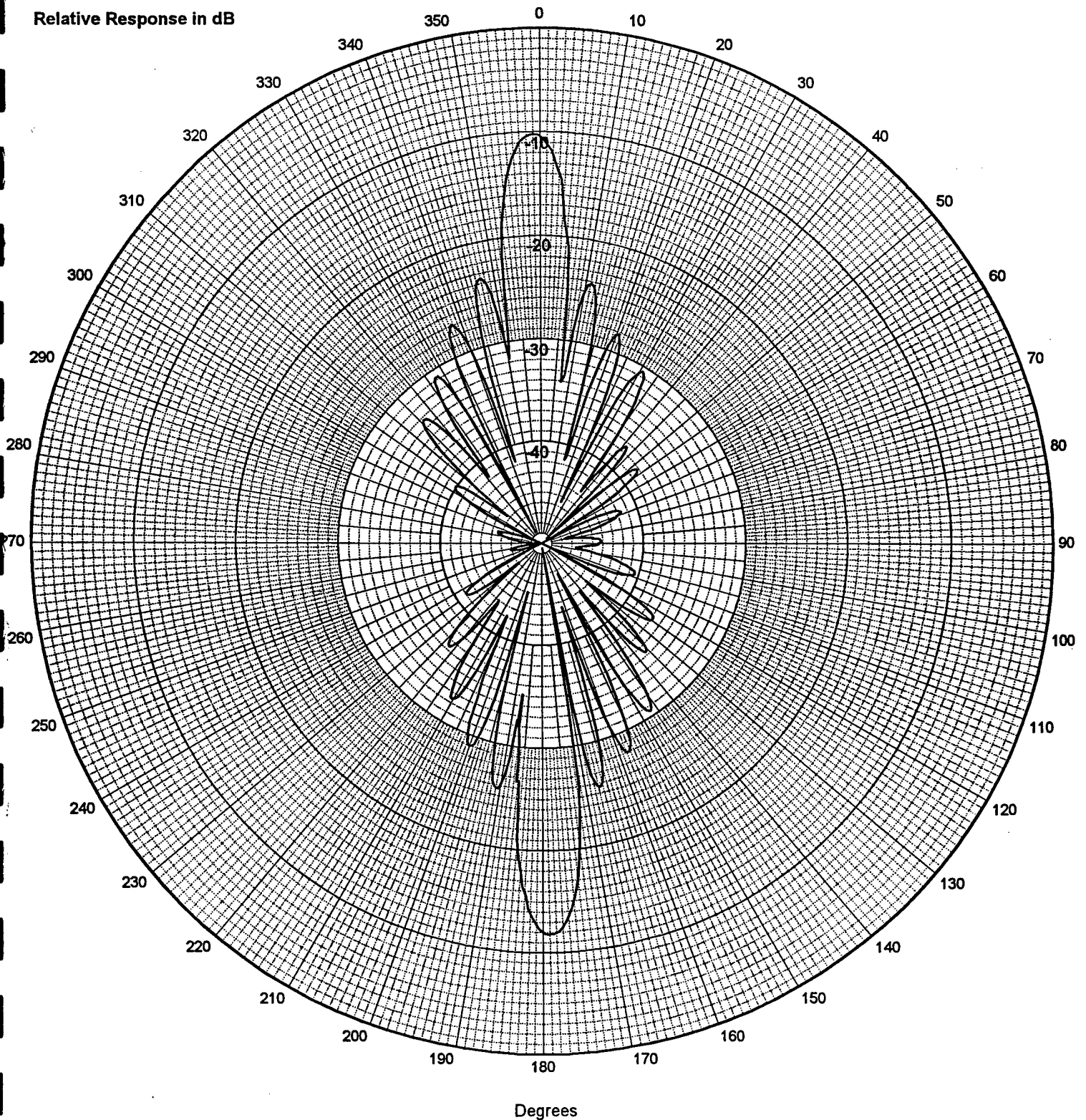
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-136  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

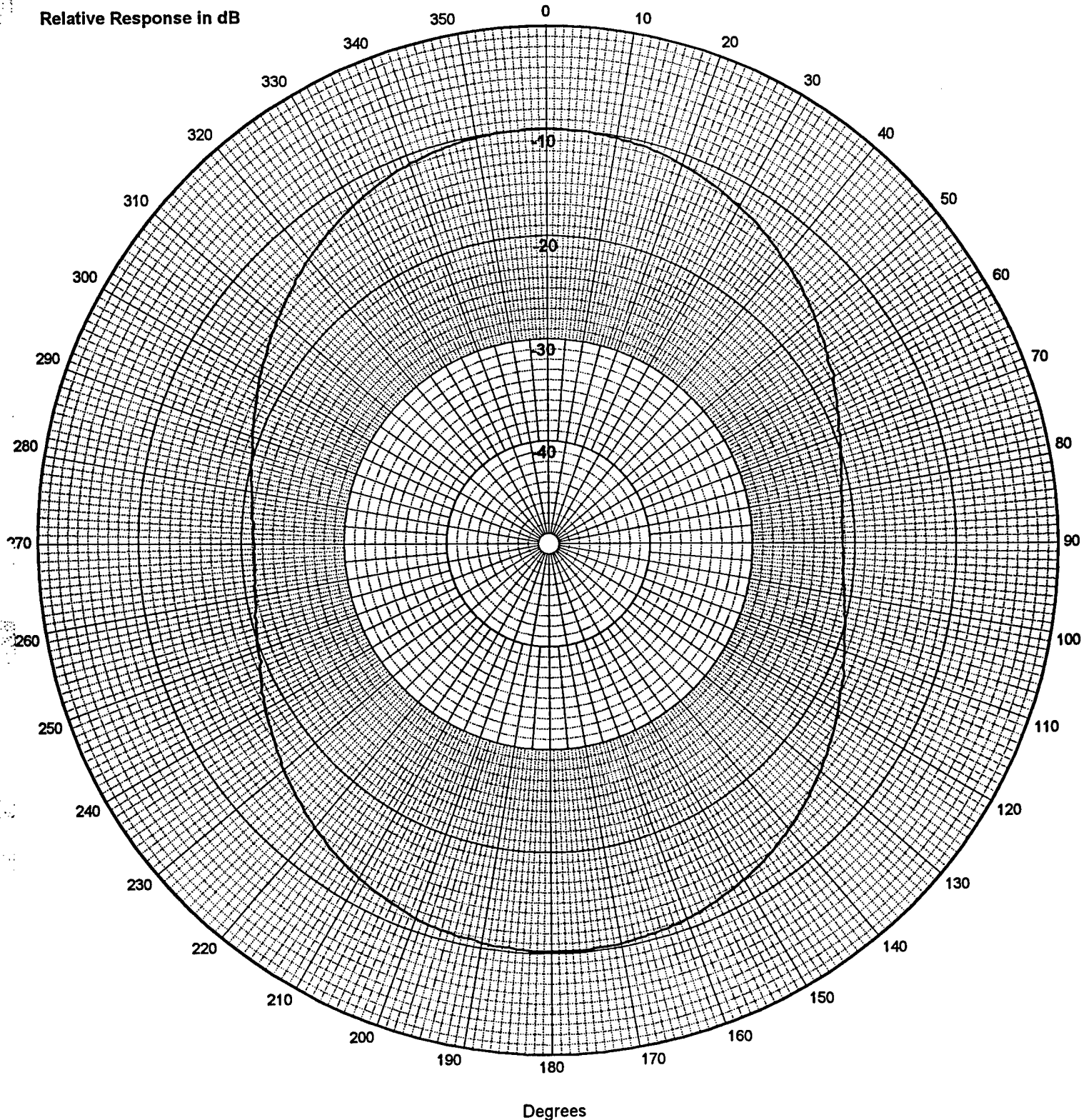
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

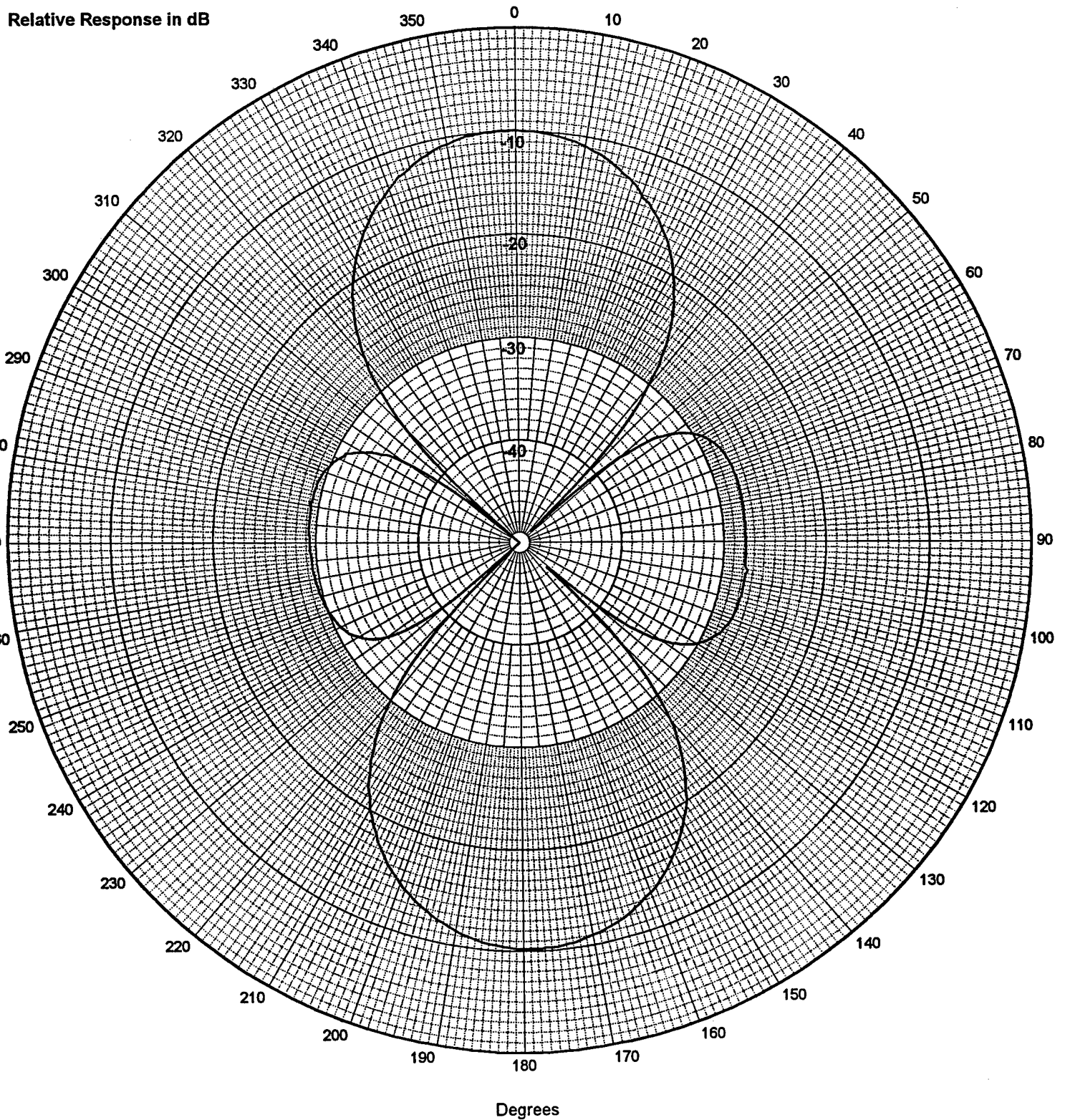




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

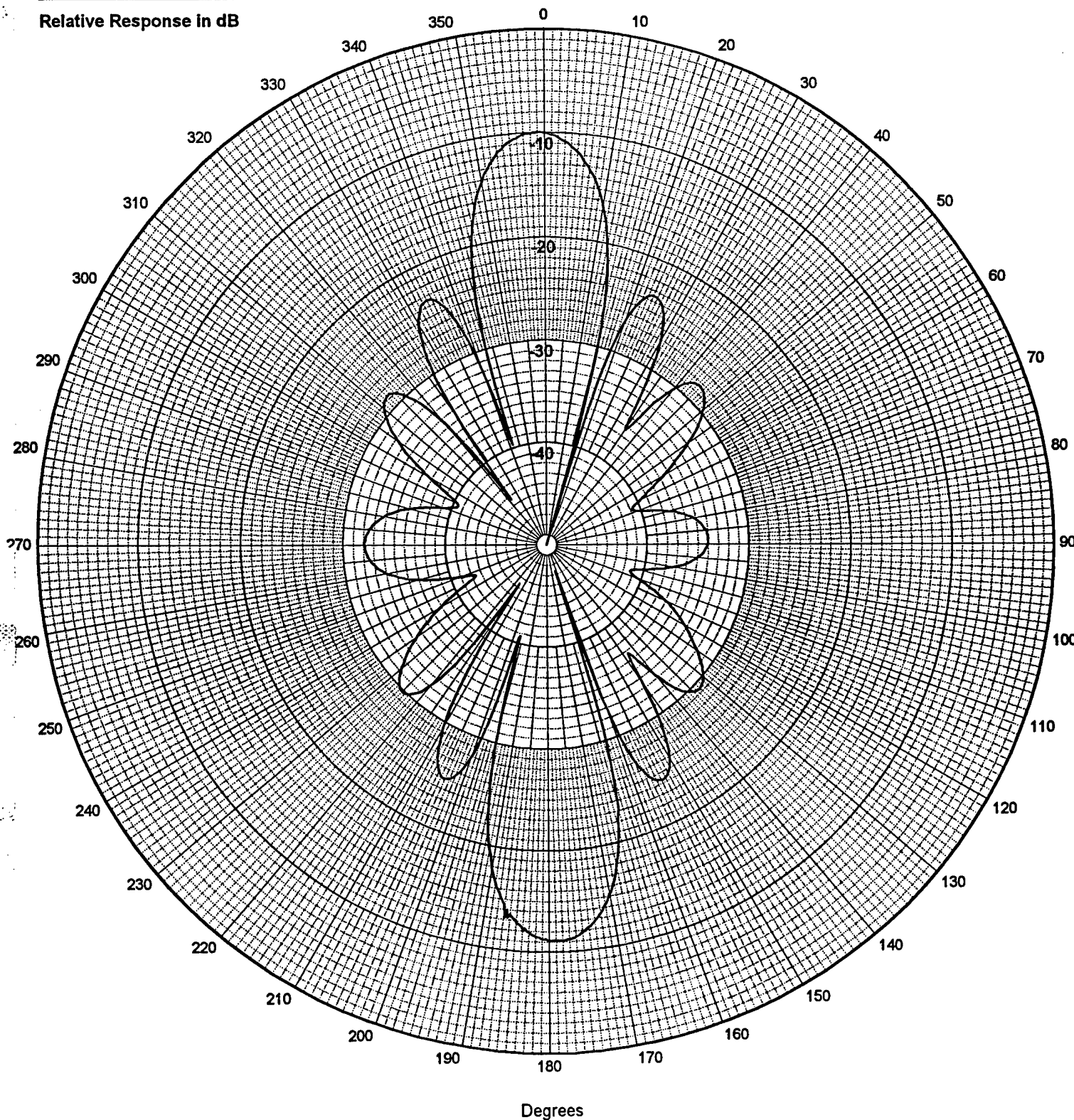
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0727-140  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 6895 kPa ( 703.1 m )

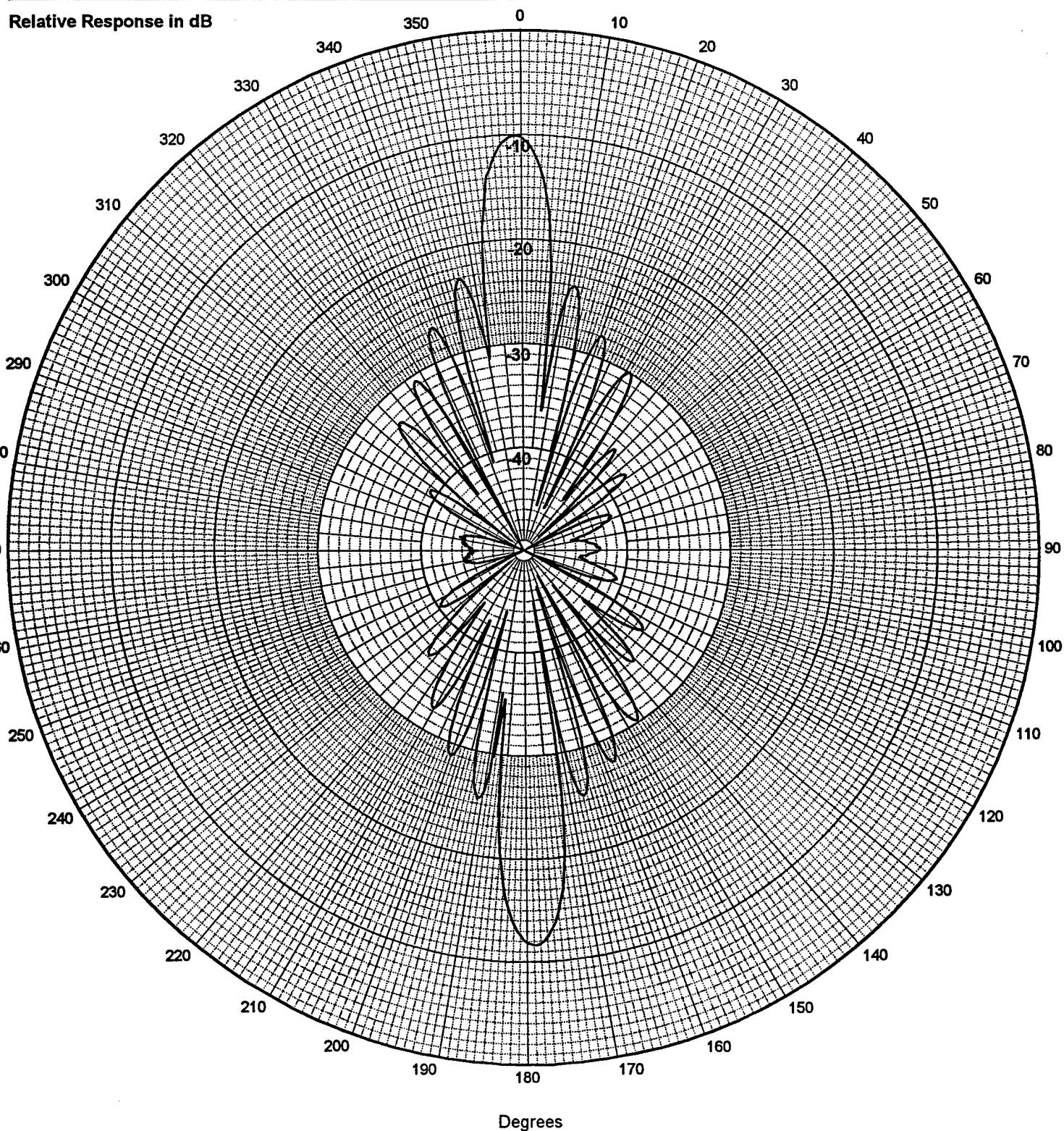
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

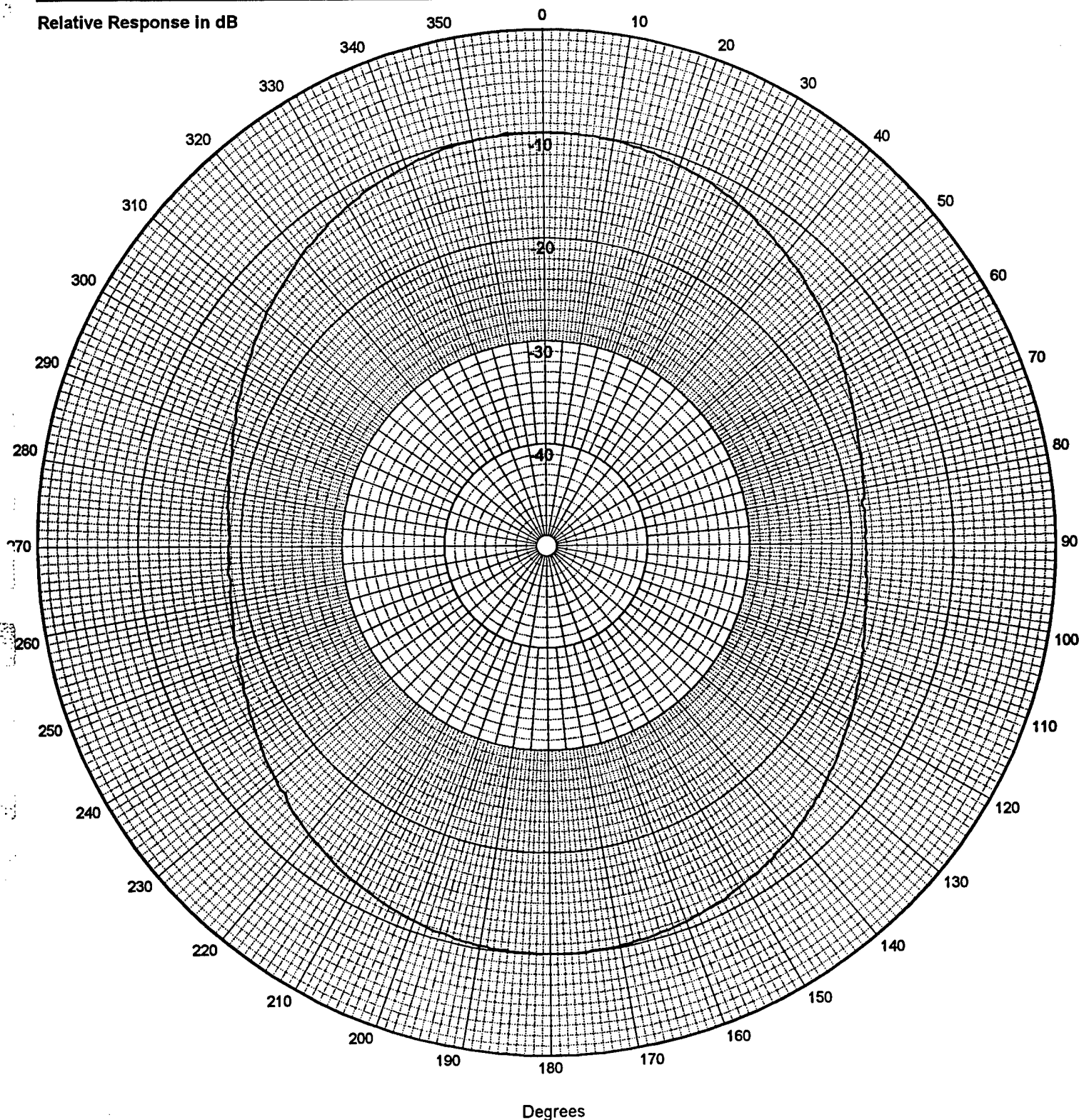
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB





NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0727-142  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

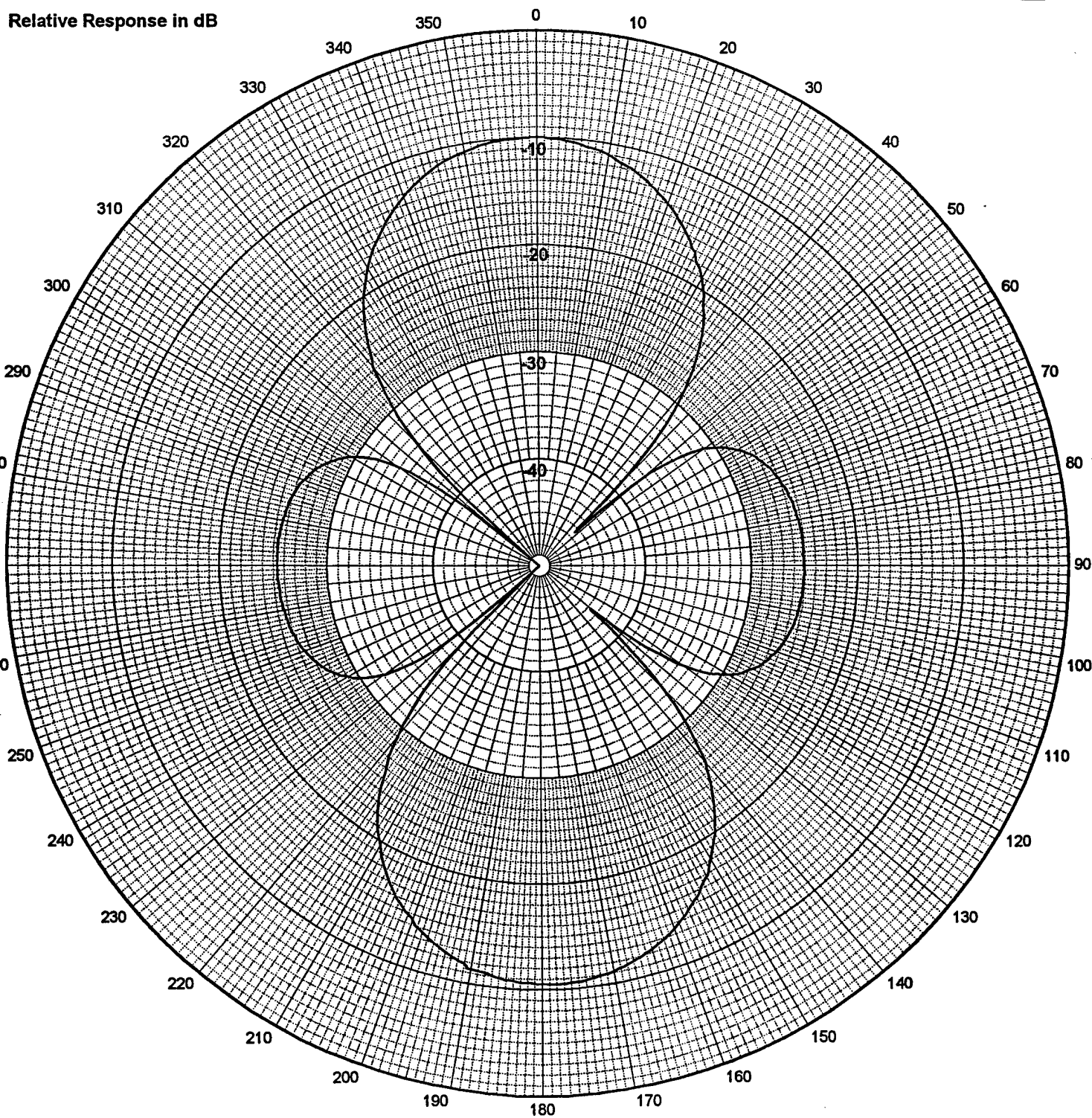
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



Degrees



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

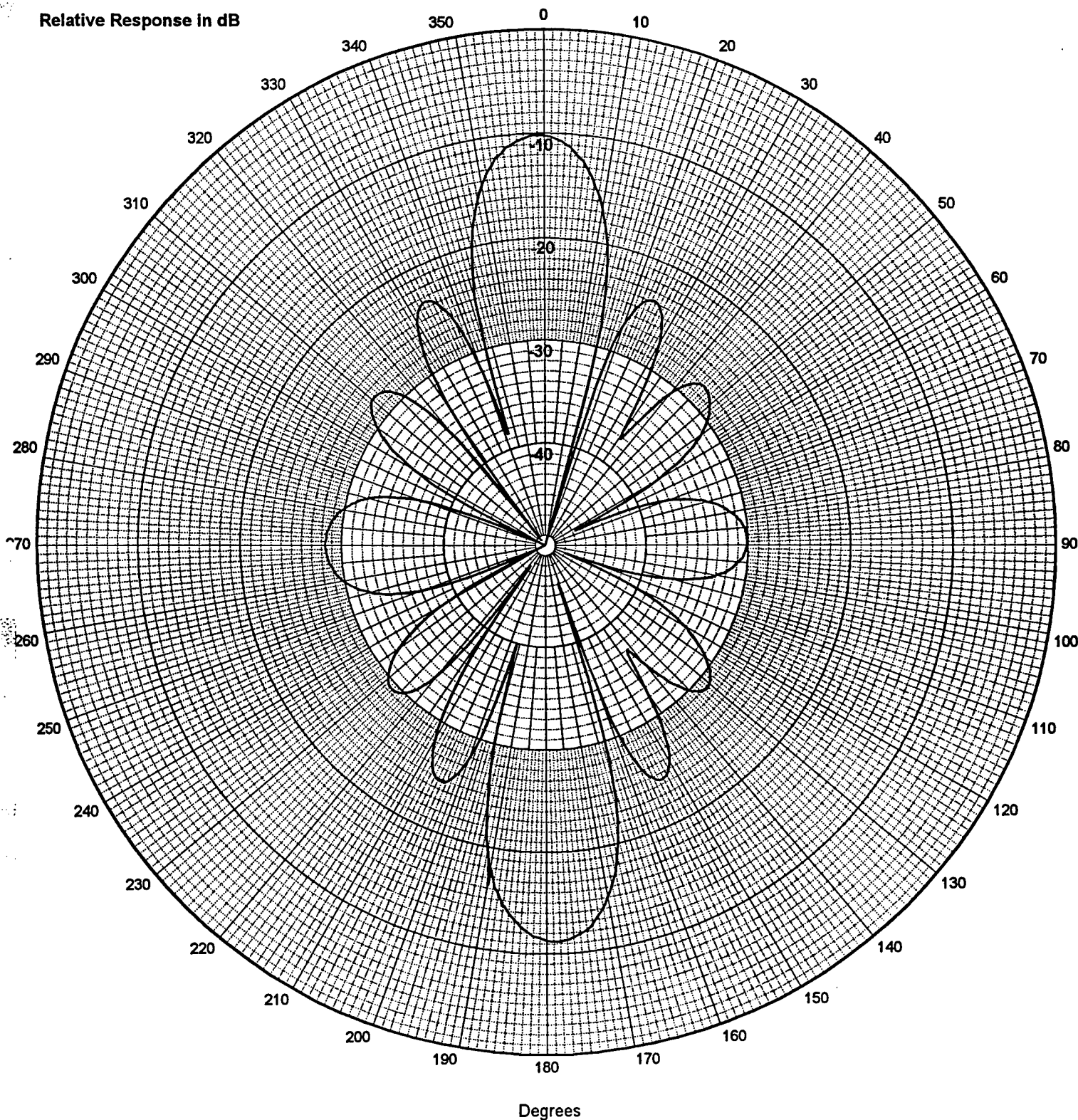
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-144  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-10P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

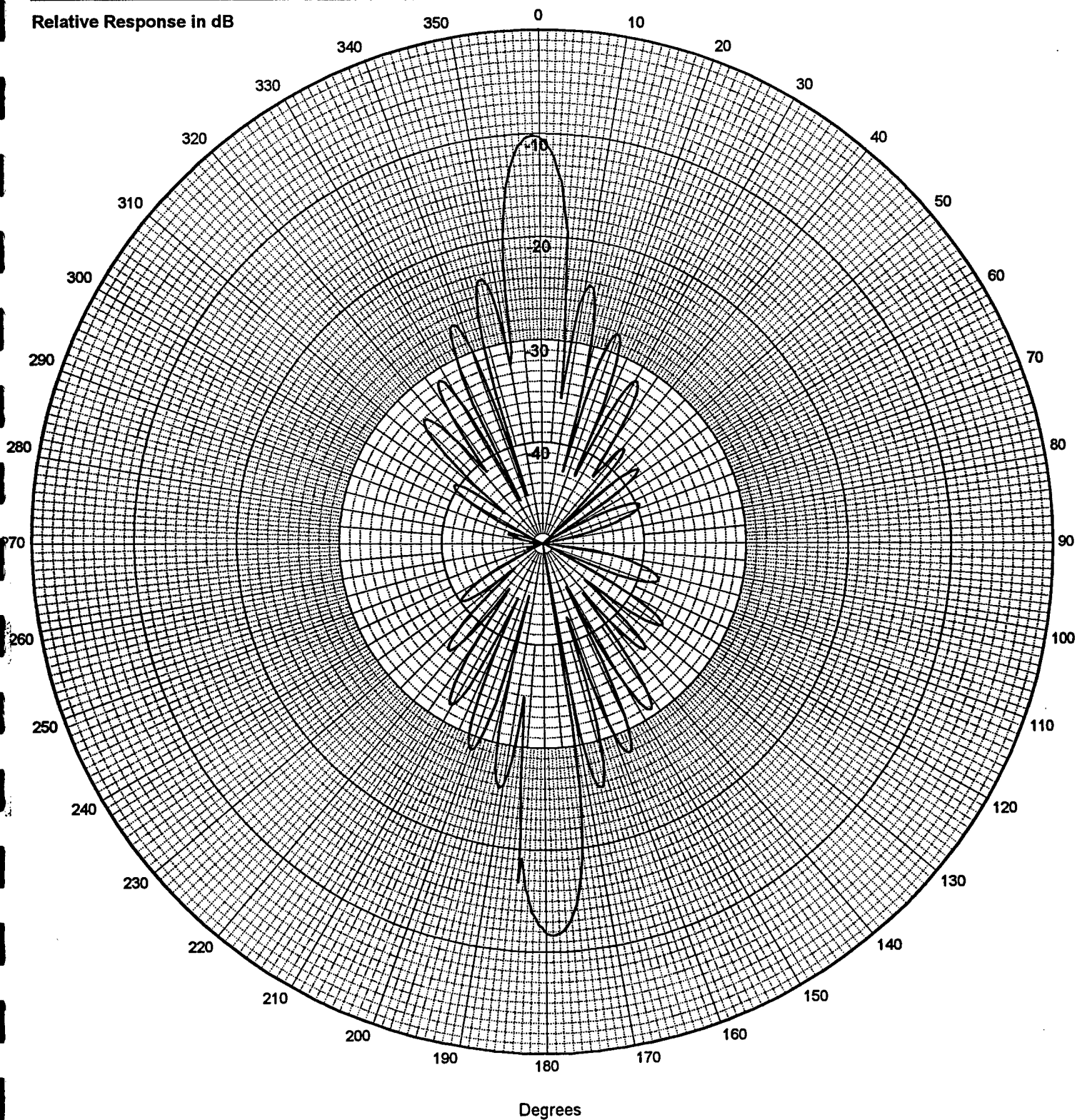
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB



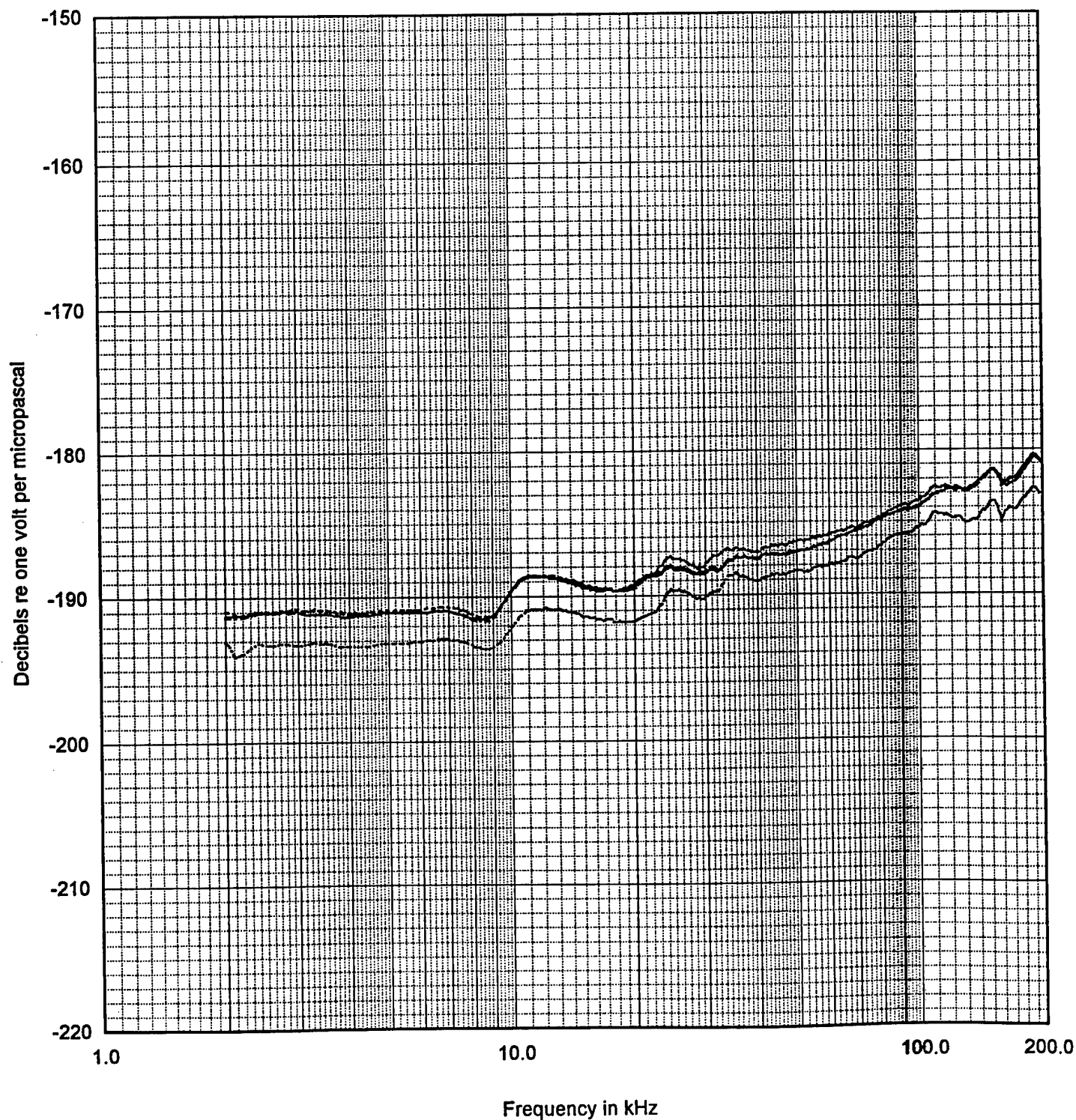
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-11P4

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
- . . . . 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



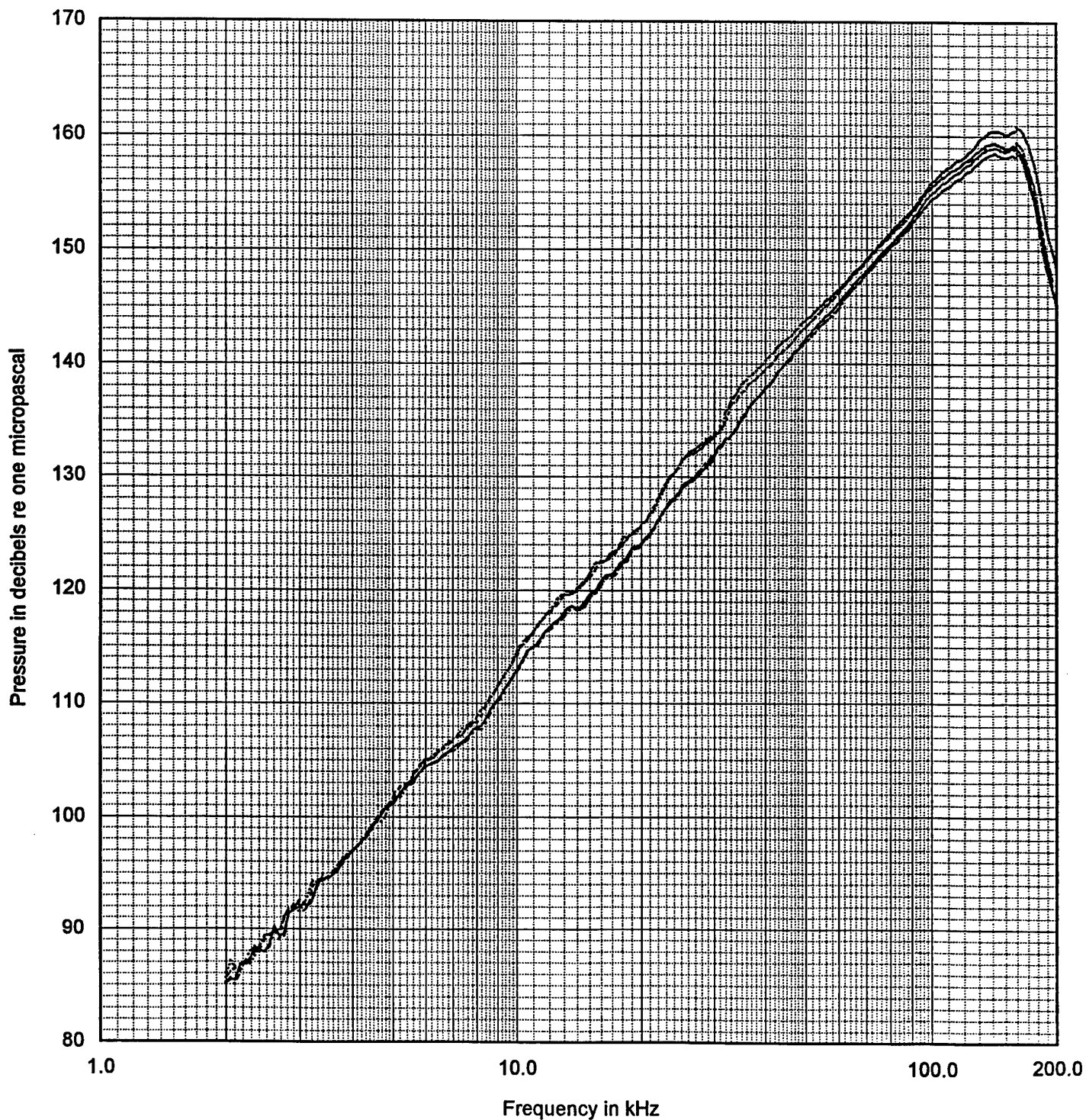
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-11P4

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure





30° 20° 10° 0 350° 340° 330° 10° 20° 30°

USRD NO: 0727-147  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

147  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
Before Pressure  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

150° 160° 170° 180° 190° 200° 210°  
210° 200° 190° 180° 170° 160° 150°

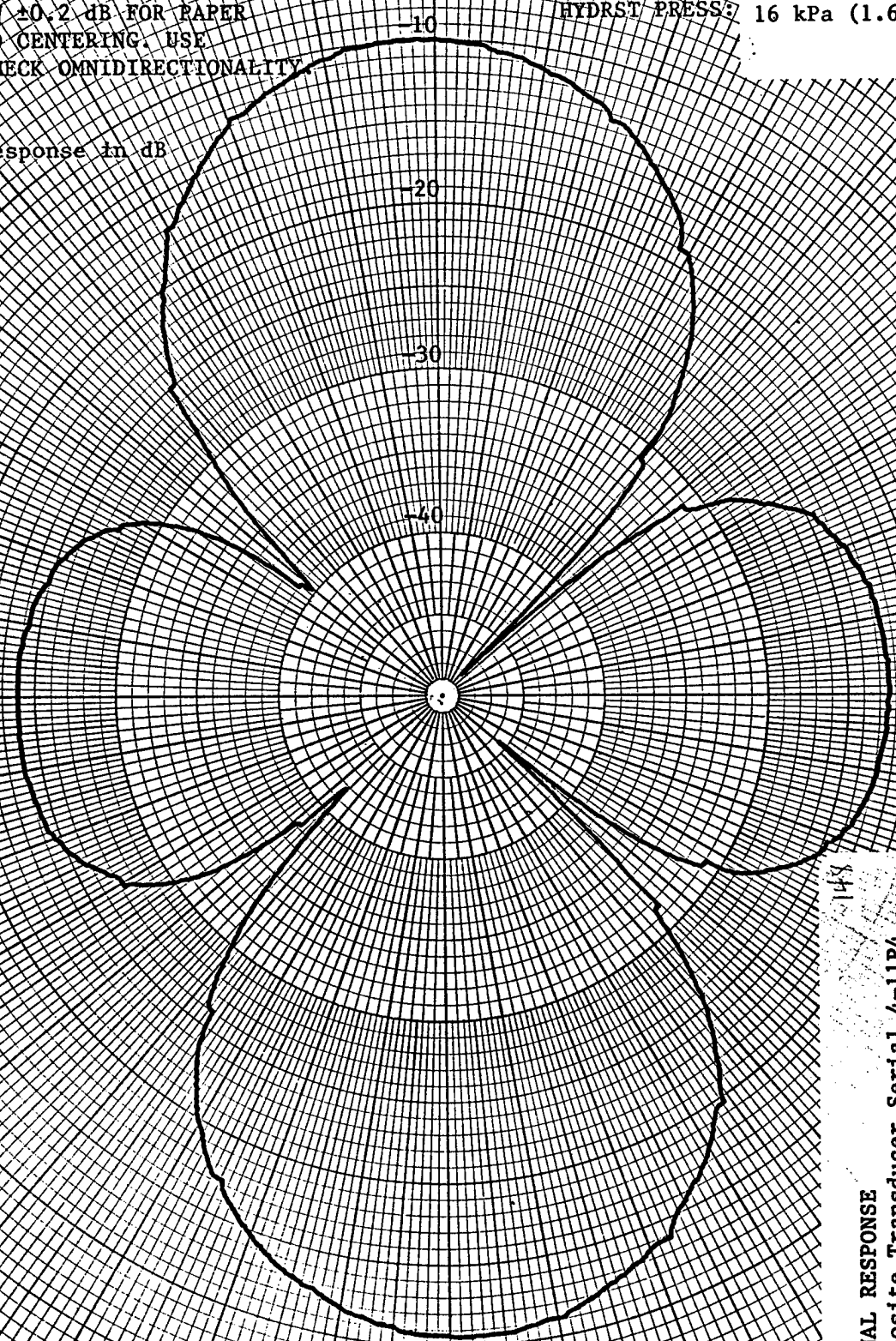


30° 20° 10° 0 350° 340° 330° 320° 310° 300° 290° 280° 270° 260° 250° 240° 230° 220° 210° 200° 190° 180° 170° 160° 150°

USRD NO: 0727-148  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW +0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
Before Pressure  
XY Plane  
20 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

10°  
20°

60°  
810°

50°  
00°

70°  
290°

80°  
180°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

320°  
40°

310°  
50°

300°  
60°

290°  
70°

280°  
80°

270°  
90°

260°  
100°

250°  
110°

240°  
120°

230°  
130°

220°  
140°

150°  
210°

160°  
200°

170°  
190°

180°  
180°

190°  
170°

200°  
160°

210°  
150°

USRD NO:

0727-149

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

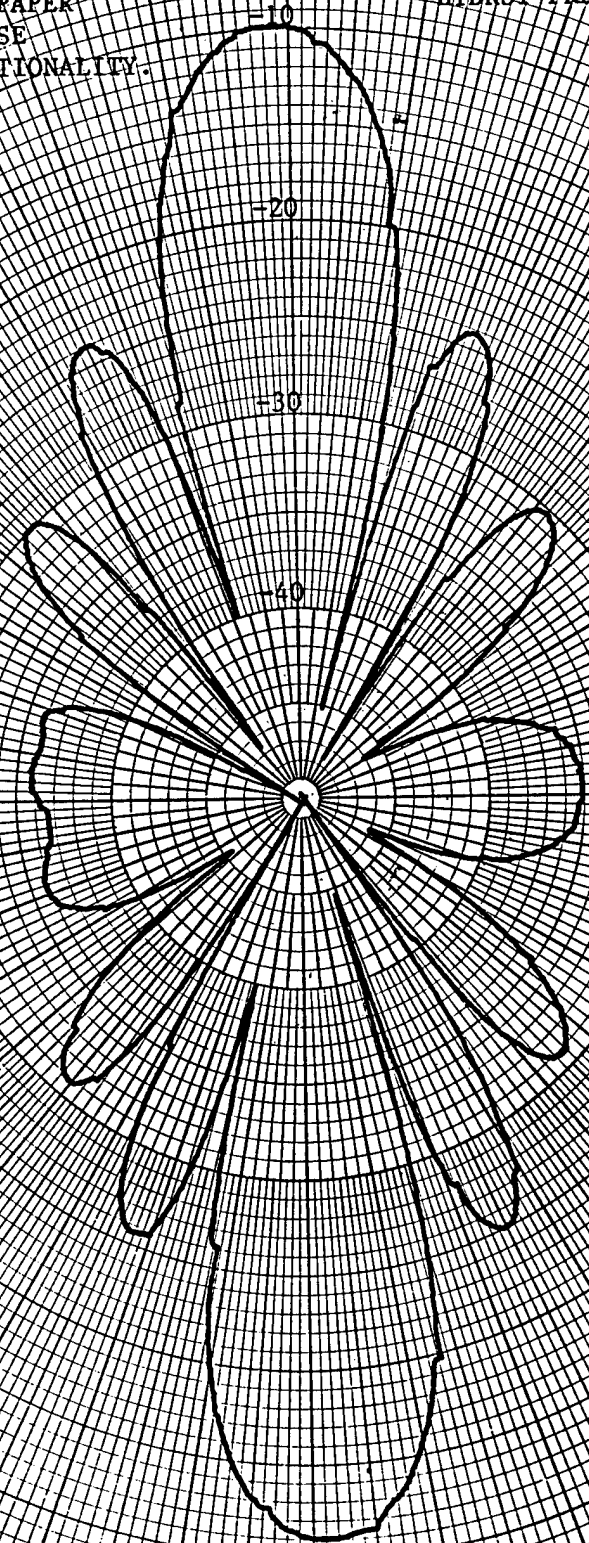
4°C

HYDRST PRESS:

16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
Before Pressure  
XY Plane  
50 kHz

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

USRD NO: 0727-150  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

150  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
Before Pressure  
XY Plane  
100 kHz



30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°10°  
20°30°  
810°50°  
00°70°  
290°80°  
180°90°  
170°00°  
160°110°  
250°120°  
240°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-151  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

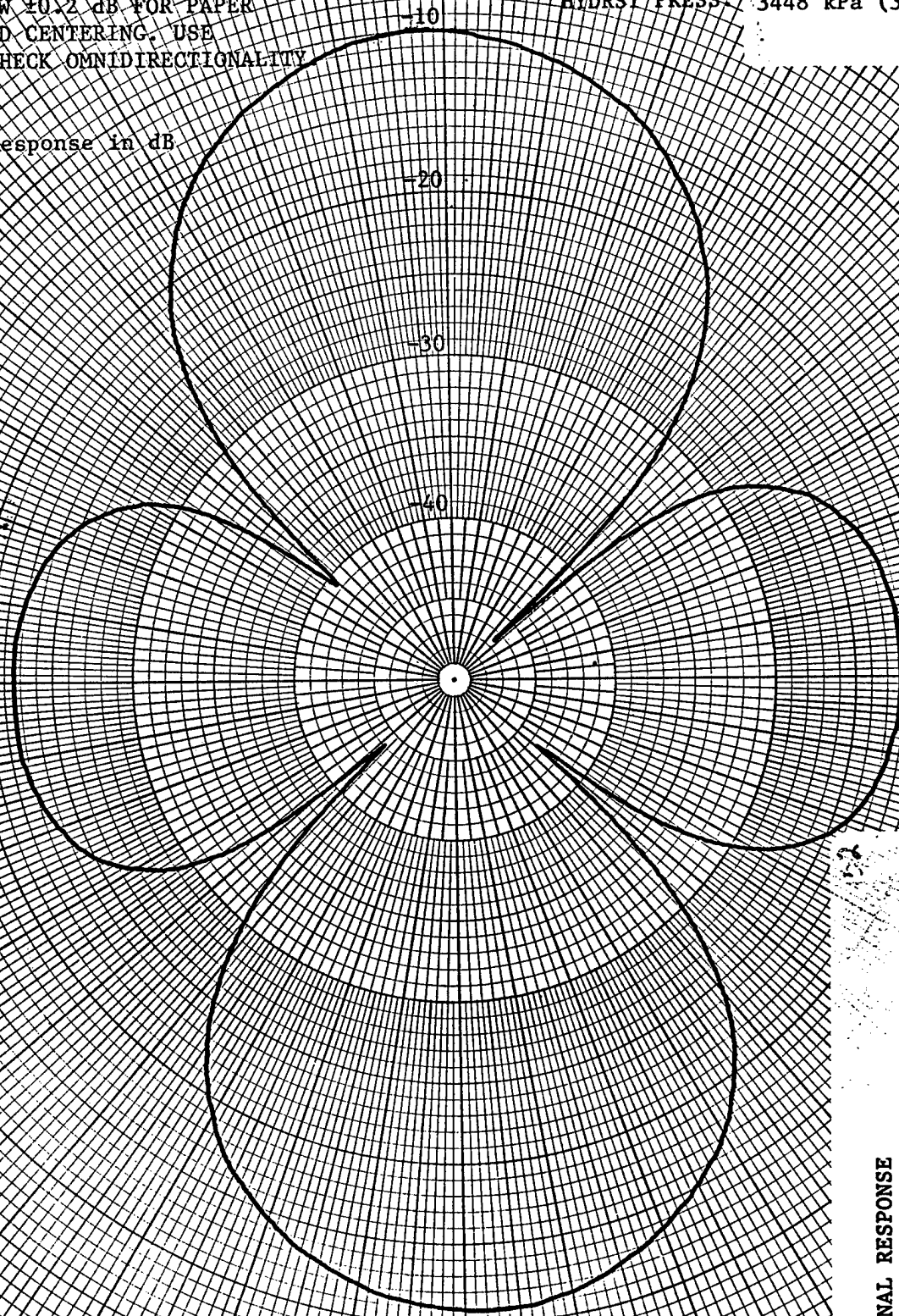
150°  
210°160°  
200°170°  
190°180°  
180°190°  
170°200°  
160°210°  
150°

30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-152  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
XY Plane  
20 kHz

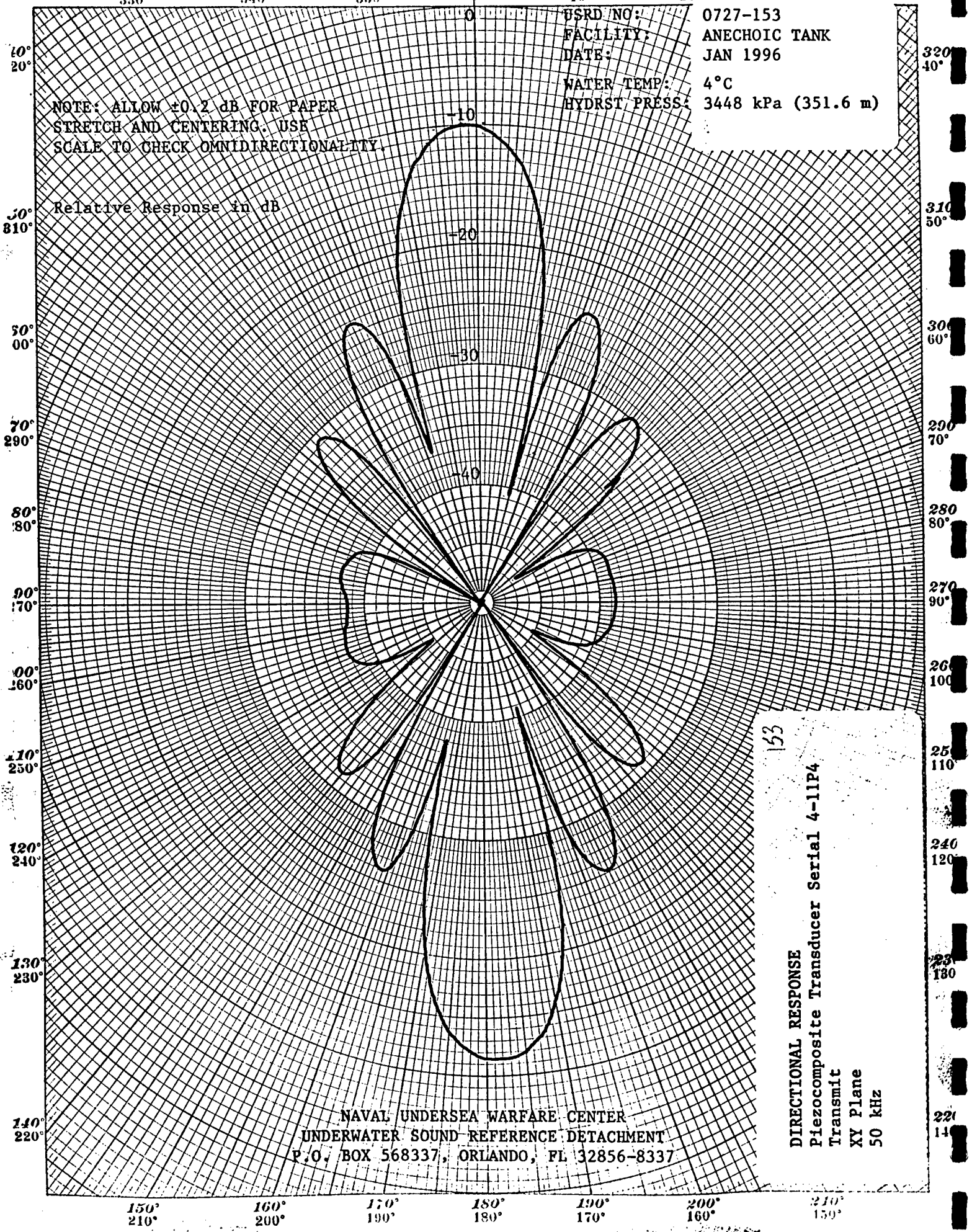


30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

USRD NO: 0727-153  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

153  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
XY Plane  
50 kHz

30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

USRD NO: 0727-154  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 3448 kPa (351.6 m)

Relative Response in dB

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

154  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit XY Plane  
100 kHz

30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°10°  
20°50°  
810°50°  
00°70°  
290°80°  
80°90°  
170°00°  
160°110°  
250°120°  
240°130°  
230°140°  
220°320°  
40°310°  
50°300°  
60°290°  
70°280°  
80°270°  
90°260°  
100°250°  
110°240°  
120°230°  
130°220°  
140°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-155  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

155  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

150°  
210°160°  
200°170°  
190°180°  
180°190°  
170°200°  
160°210°  
150°



30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO:

0727-156

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

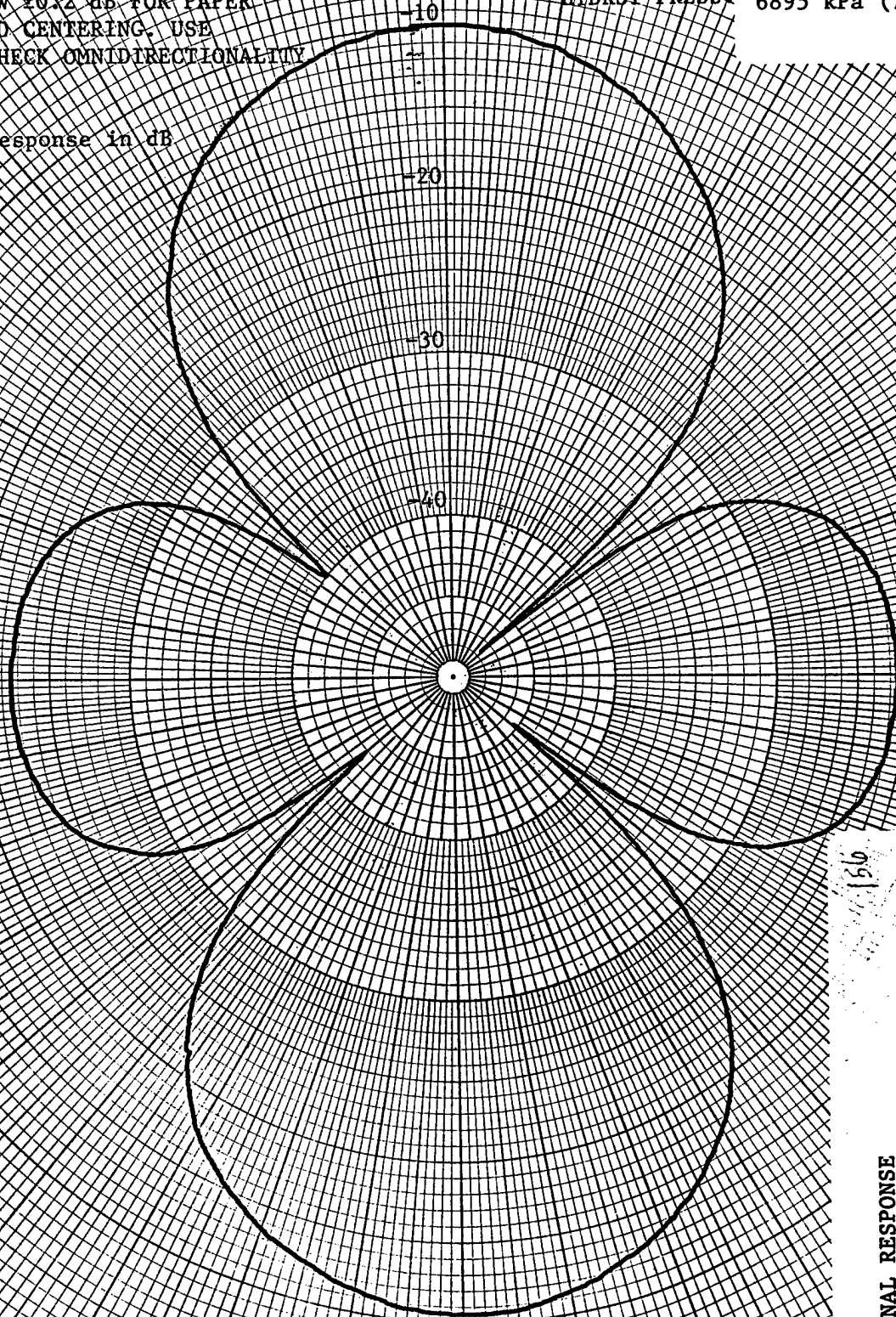
4°C

HYDRST PRESS:

6895 kPa (703.1 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
XY Plane  
20 kHz

30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-157  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 6895 kPa (703.1 m)

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

151  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
XY Plane  
50 kHz



30° 330° 20° 340° 10° 350° 0° 350° 10° 340° 20° 330° 30°

USRD NO: 0727-159  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

40° 320°  
50° 310°  
60° 300°  
70° 290°  
80° 280°  
90° 270°  
00° 260°  
10° 250°  
120° 230°  
140° 220°

320 40°  
310 50°  
300 60°  
290 70°  
280 80°  
270 90°  
260 100°  
250 110°  
240 120°  
230 130°  
220 140°

59  
DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
After Pressure  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

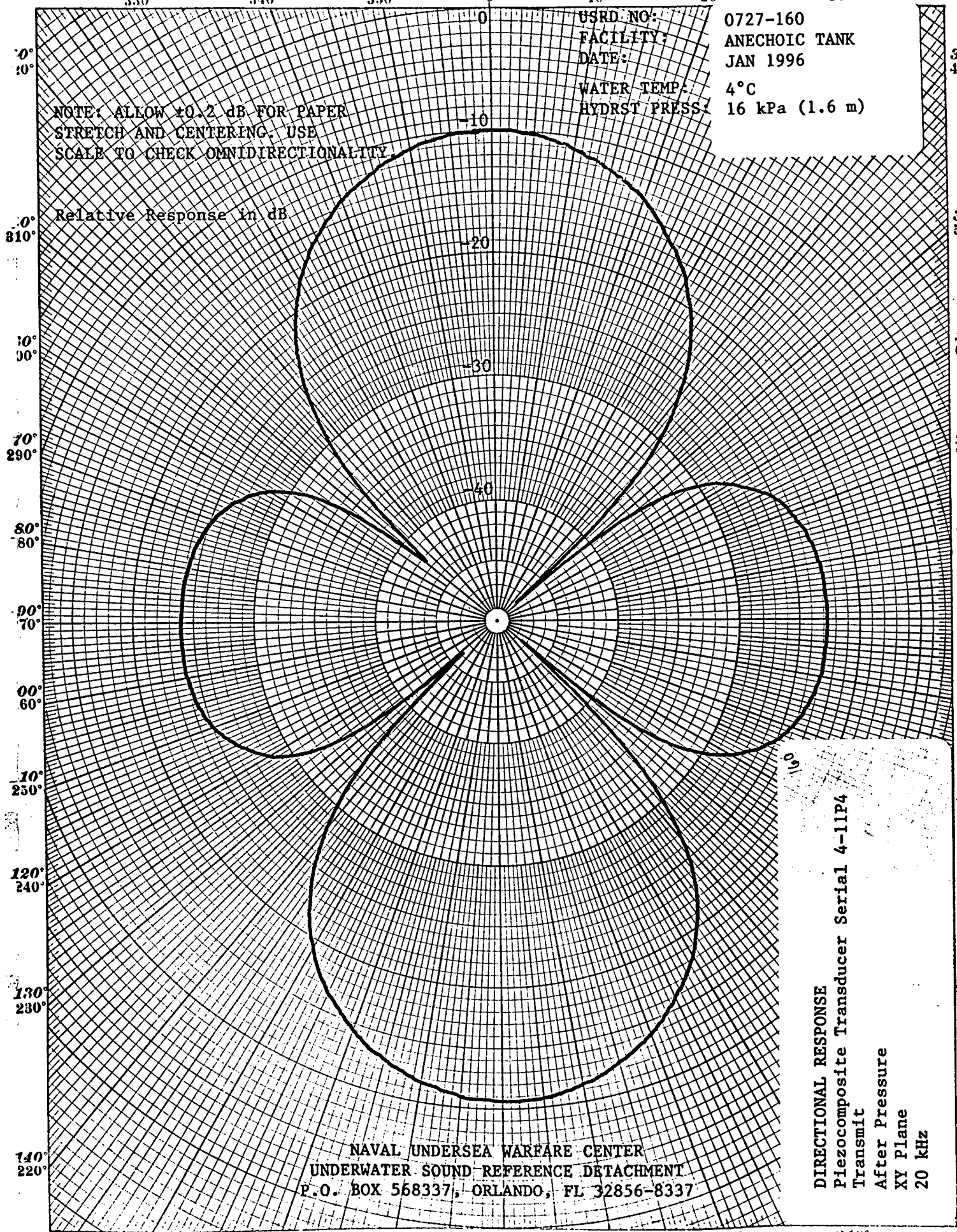
150° 210° 160° 200° 170° 190° 180° 170° 160° 150° 210° 200° 190° 180°

30° 20° 10° 0 350° 340° 330° 10° 20° 30°

USRD NO: 0727-160  
FACILITY: ANECHOIC TANK  
DATE: JAN 1996  
WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW ±0.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
After Pressure  
XY Plane  
20 kHz

320° 40°  
310° 50°  
300° 60°  
290° 70°  
280° 80°  
270° 90°  
260° 100°  
250° 110°  
240° 120°  
230° 130°  
220° 140°

30°  
330°20°  
340°10°  
350°

0°

350°  
10°340°  
20°330°  
30°USRD NO:  
FACILITY:  
DATE:0727-161  
ANECHOIC TANK  
JAN 1996WATER TEMP: 4°C  
HYDRST PRESS: 16 kPa (1.6 m)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-11P4  
Transmit  
After Pressure  
XY Plane  
50 kHz



30°  
330°20°  
340°10°  
350°

0

350°  
10°340°  
20°330°  
30°

USRD NO:

0727-162

FACILITY:

ANECHOIC TANK

DATE:

JAN 1996

WATER TEMP:

4°C

HYDRST PRESS:

16 kPa (1.6 m)

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4

Transmit

After Pressure

XY Plane

100 kHz

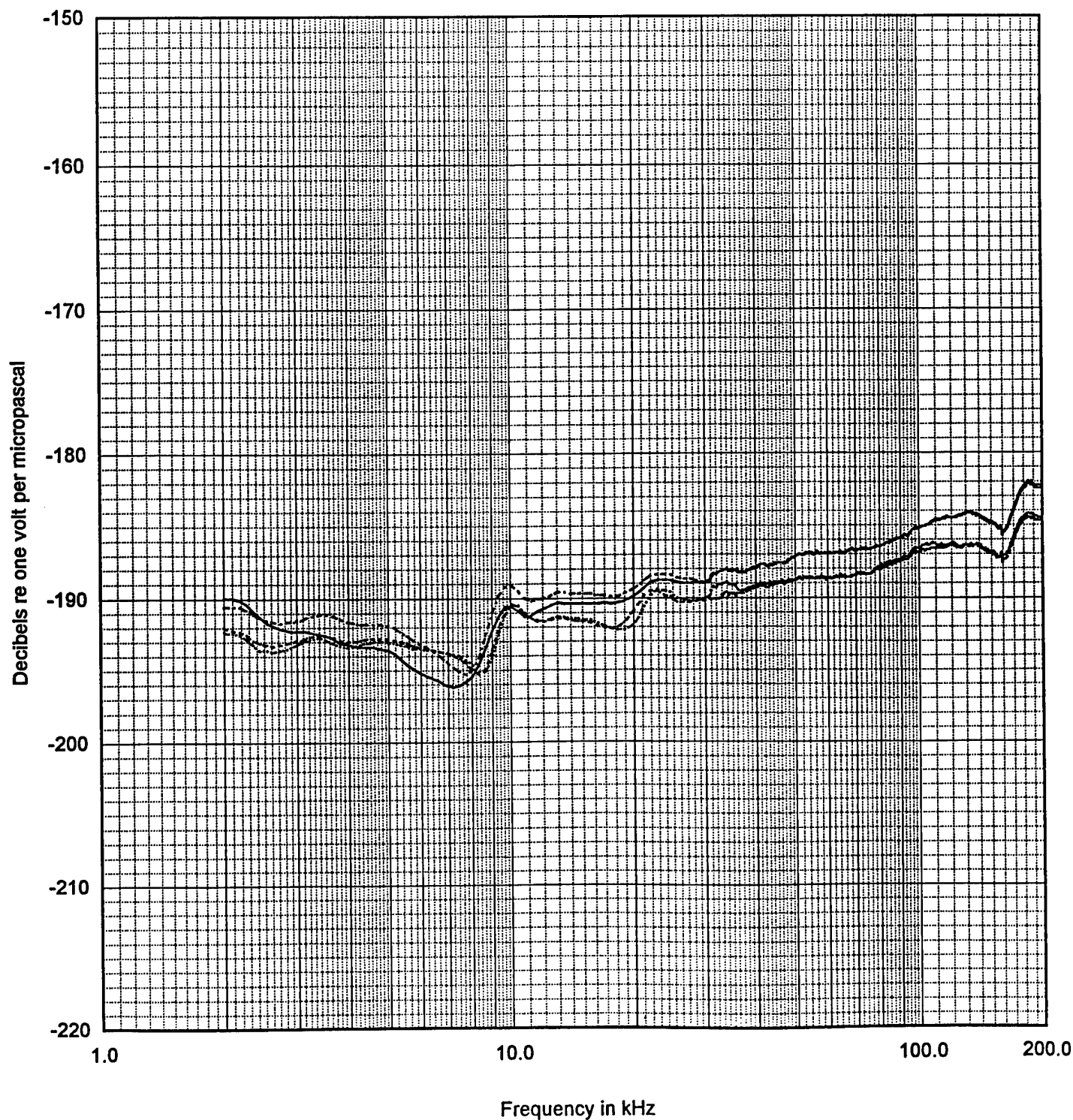
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-11P4

Open-circuit voltage measured at end of cable; Unbalanced

Water Temp: 22° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - 16 kPa ( 1.6 m) After Pressure





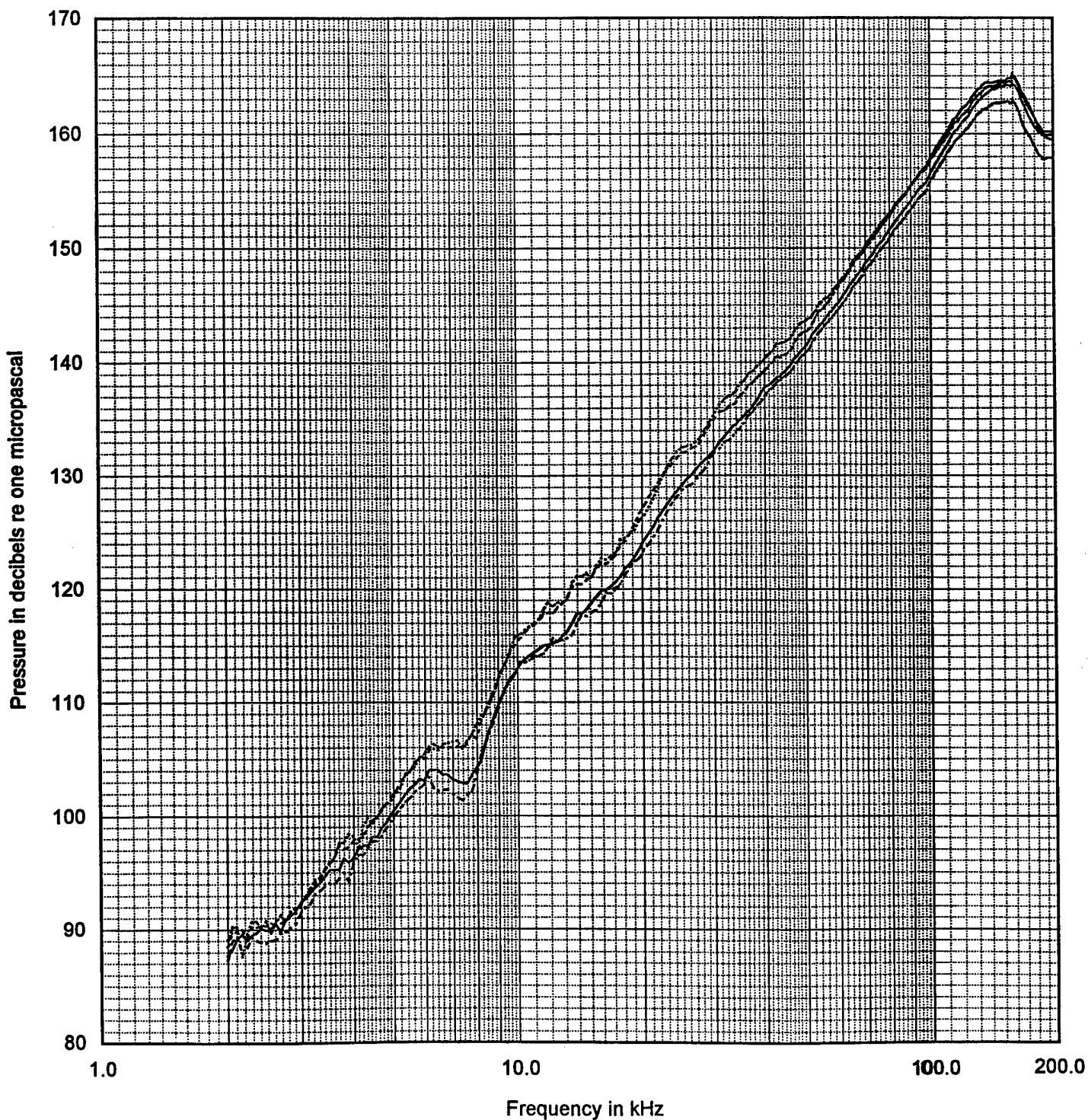
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-11P4

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

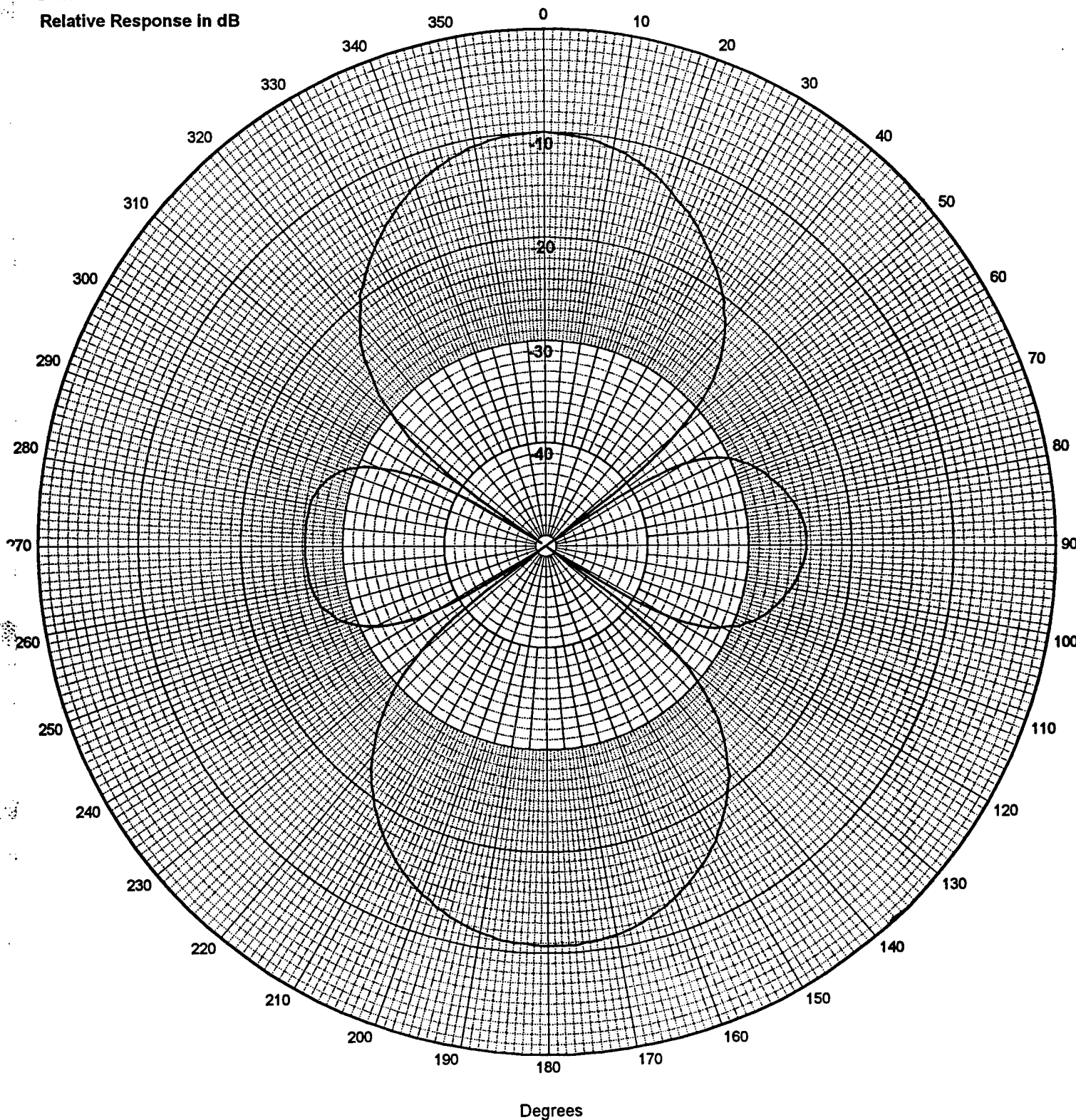
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0727-167  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

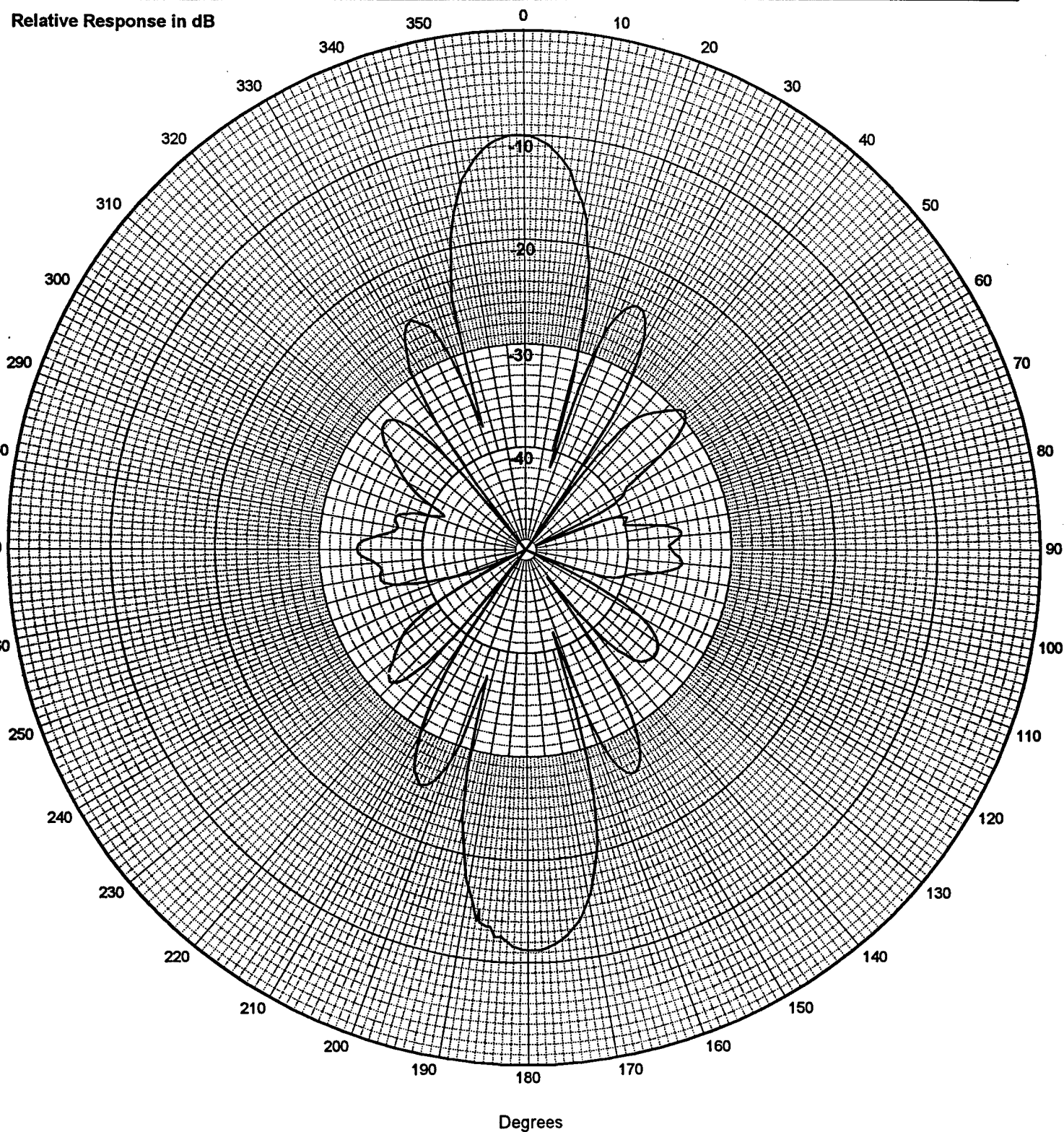
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) Before Pressure

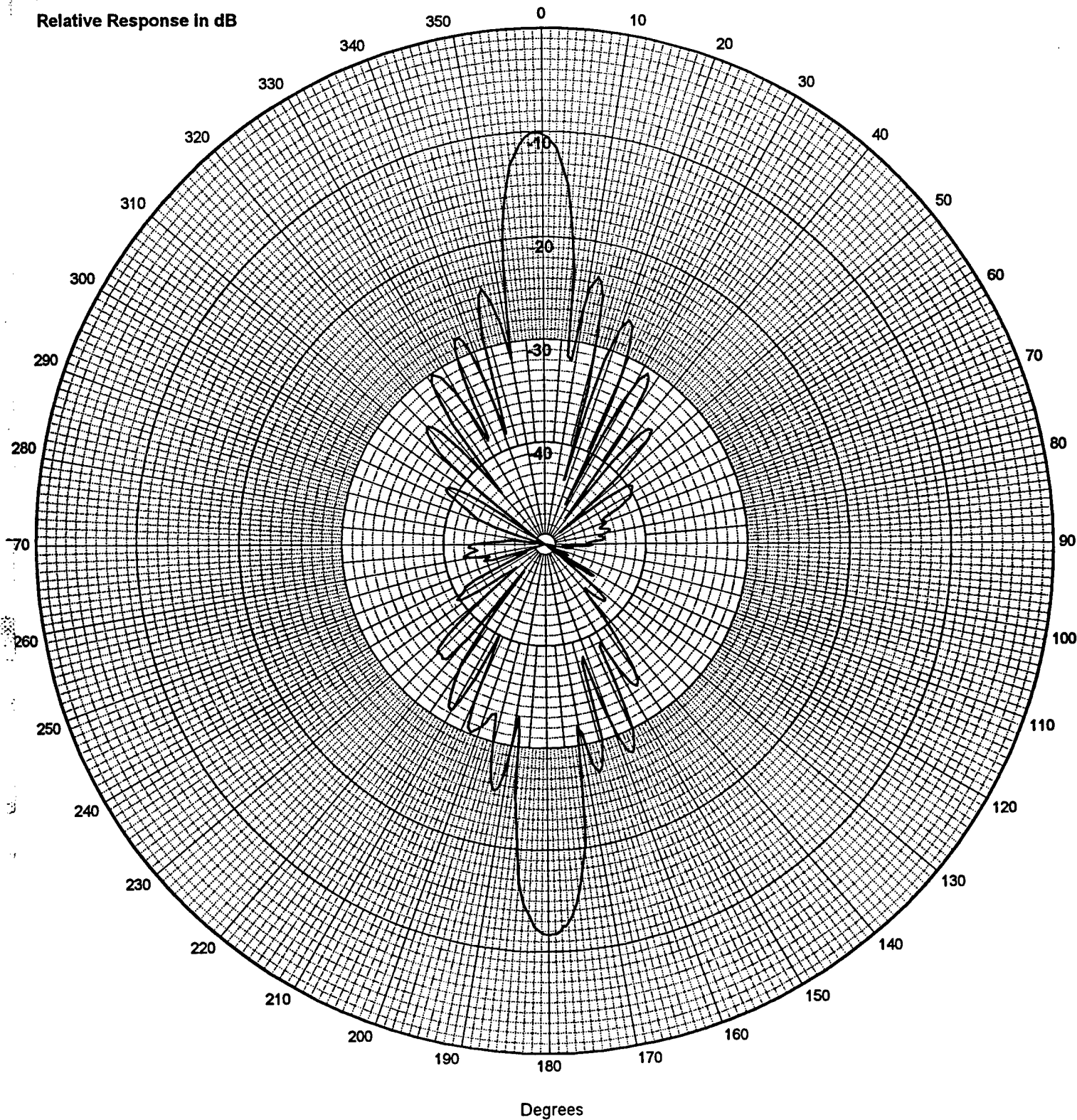
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB





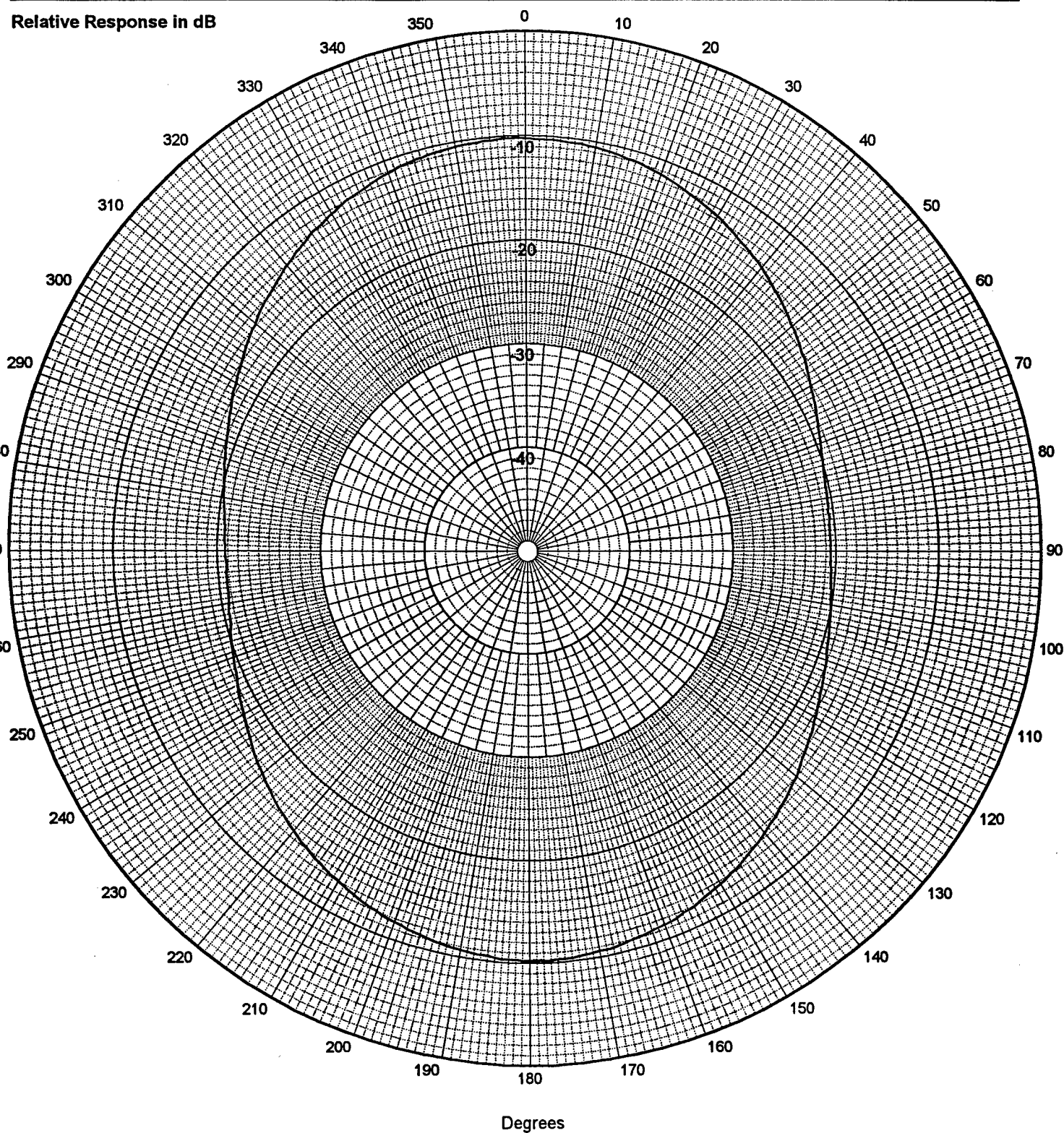
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-169  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

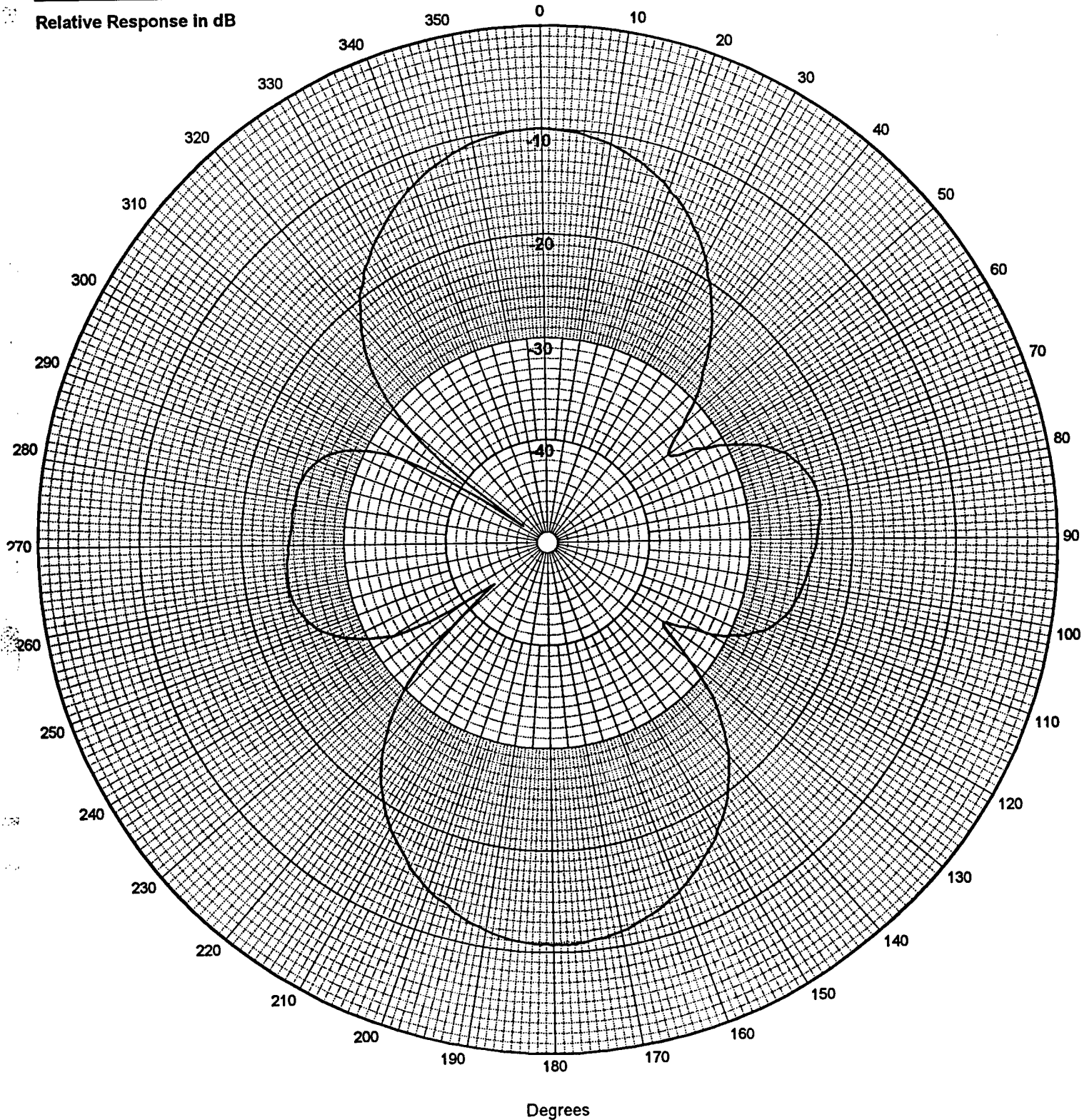
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz



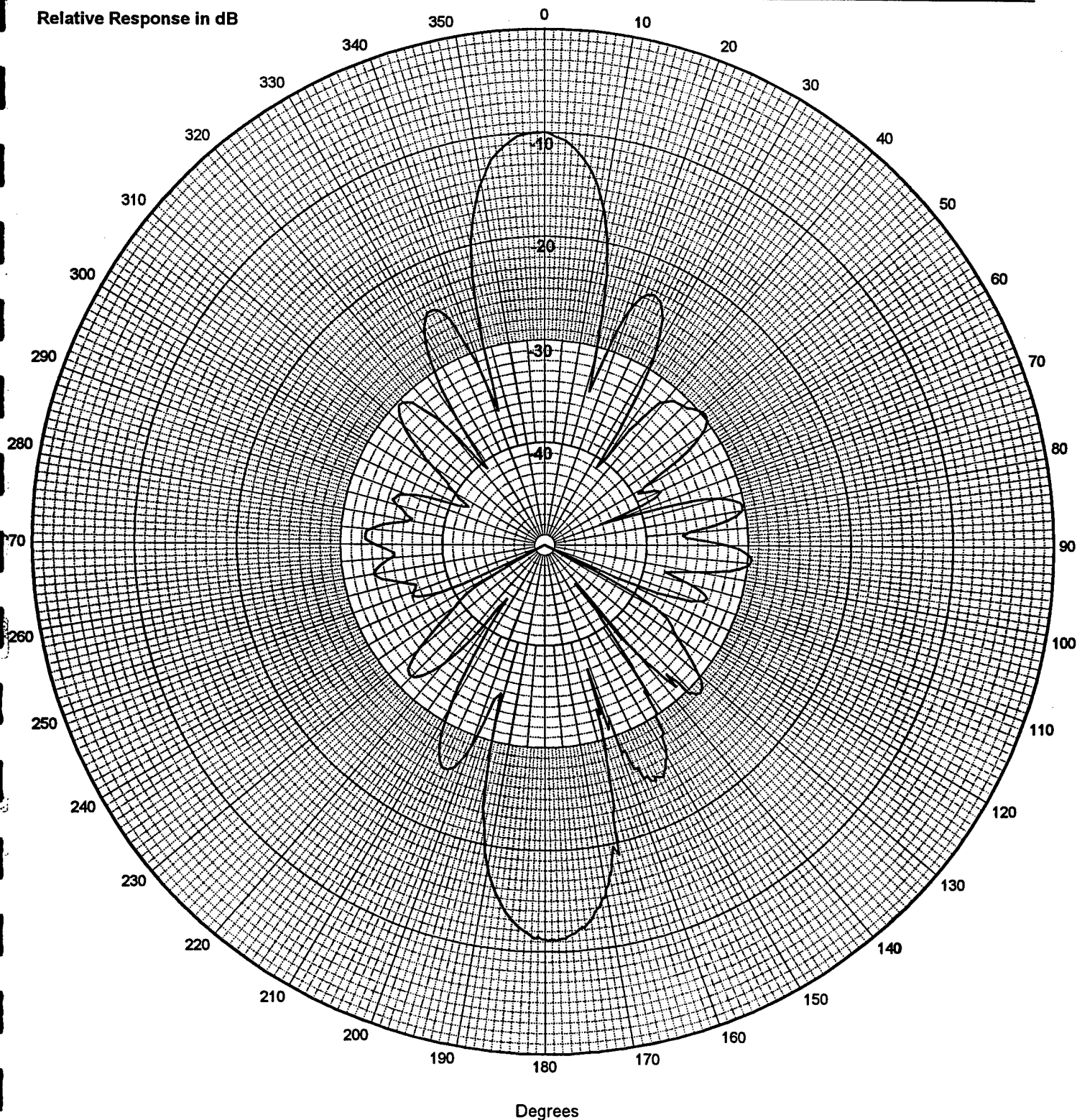
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-171  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

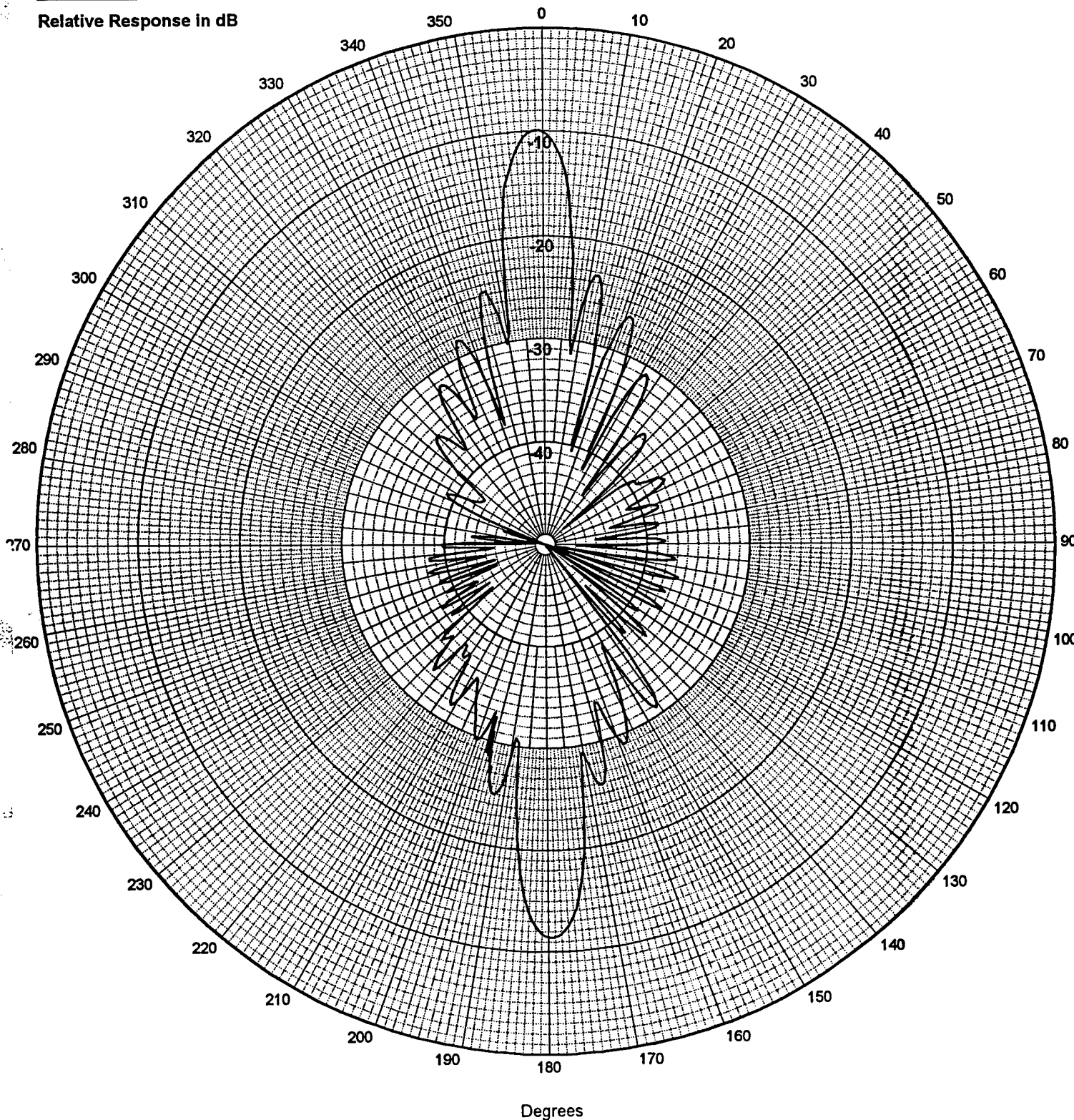
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



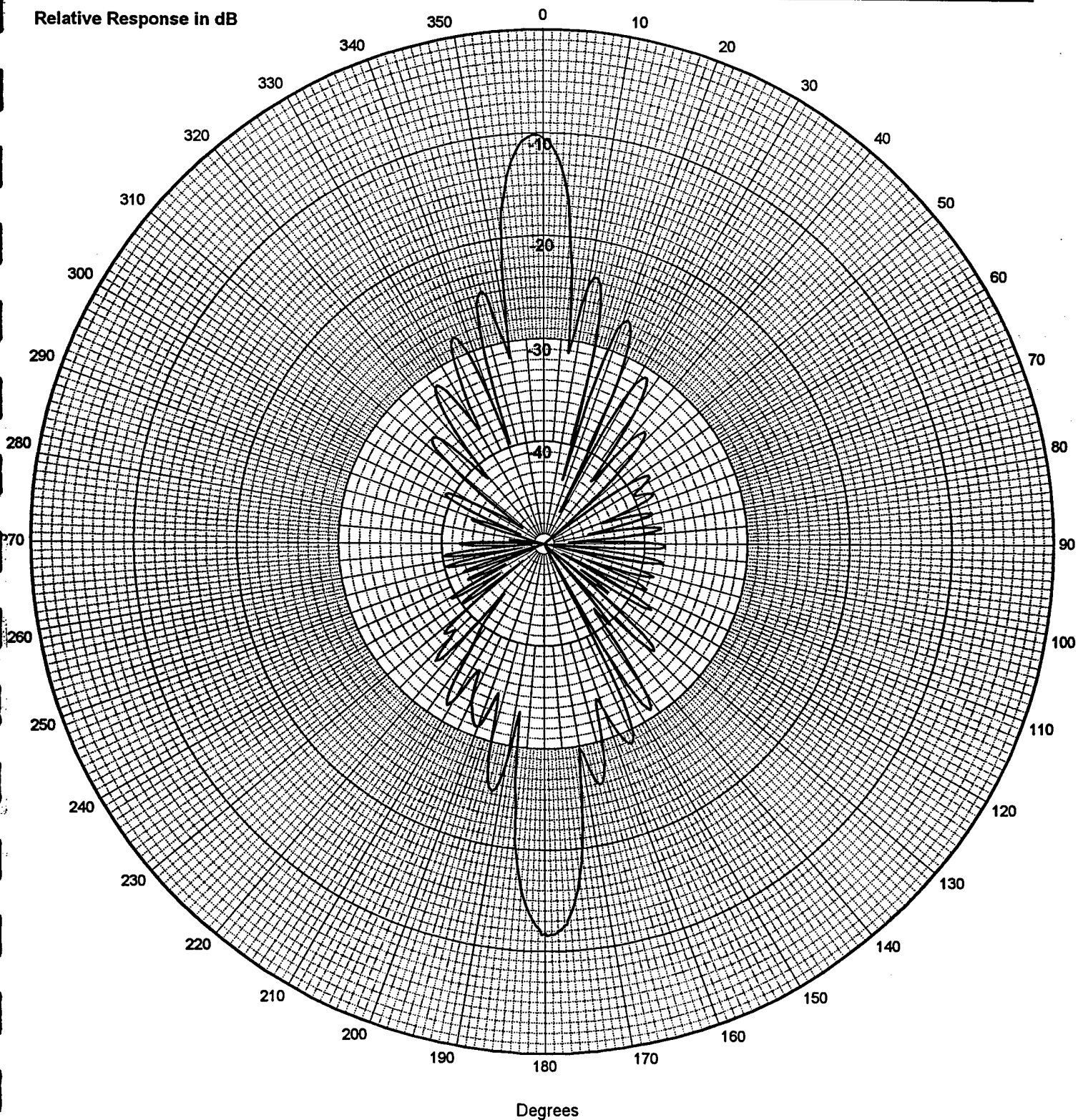
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-173  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

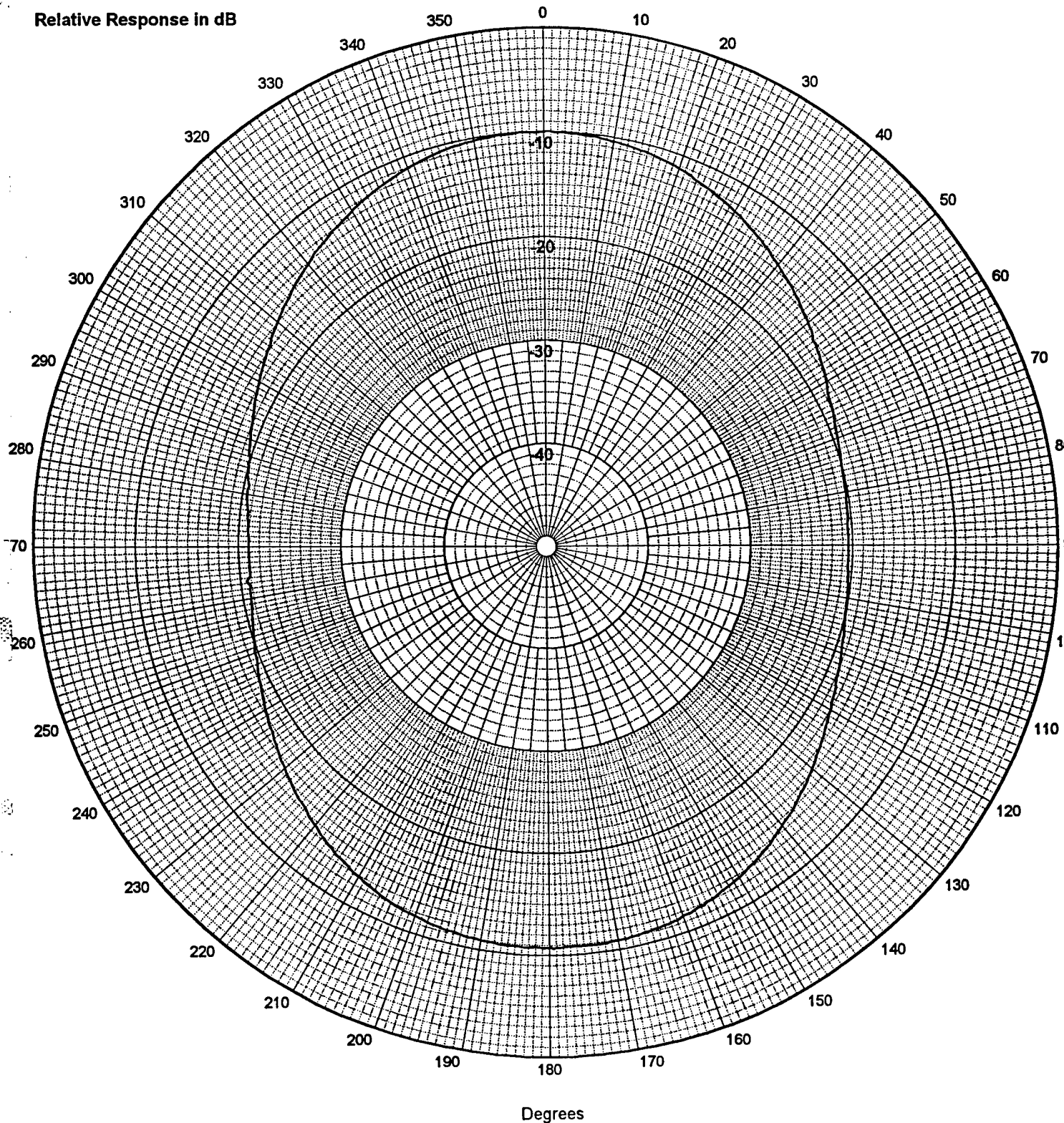
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB





NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-175  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

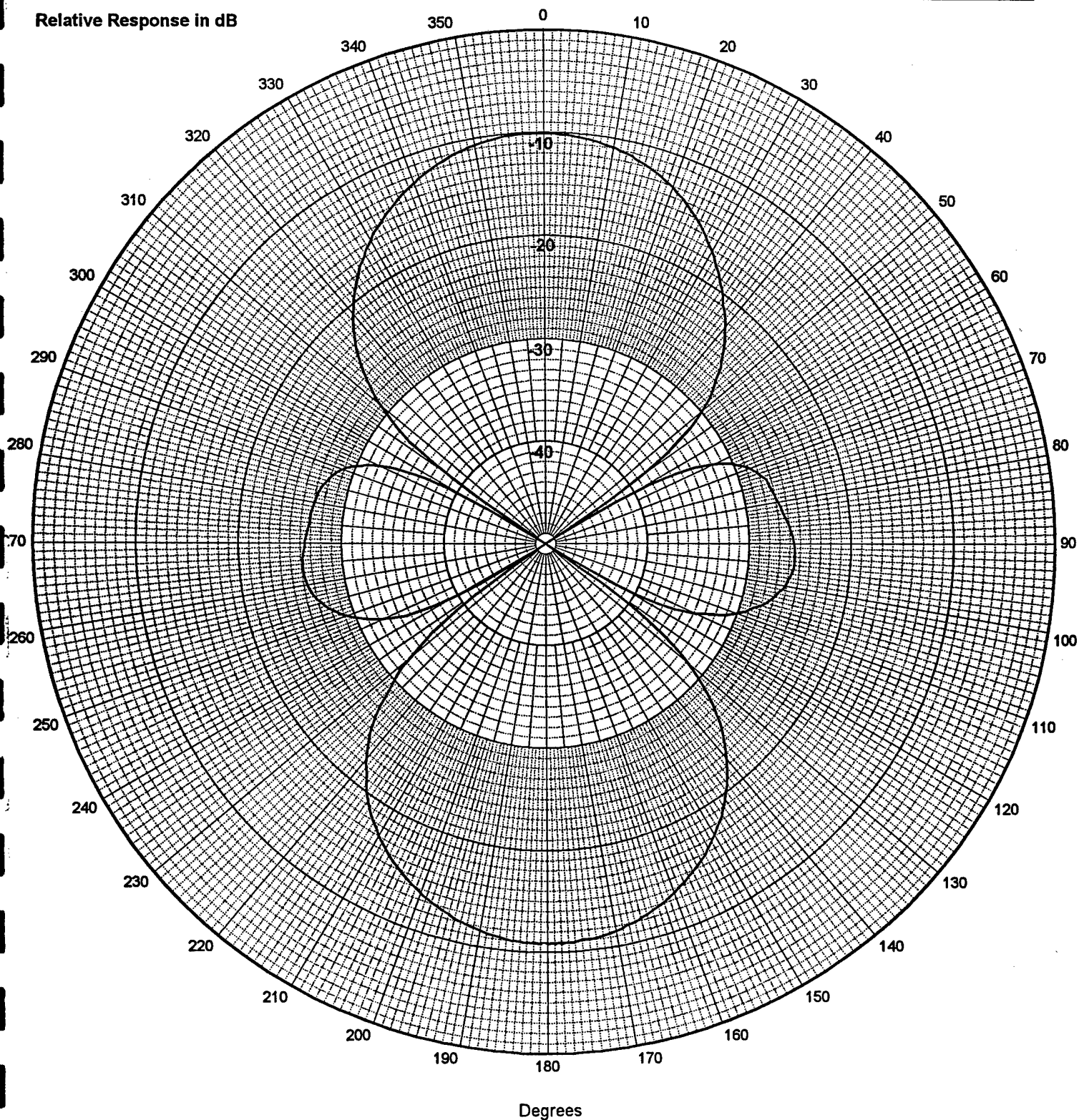
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

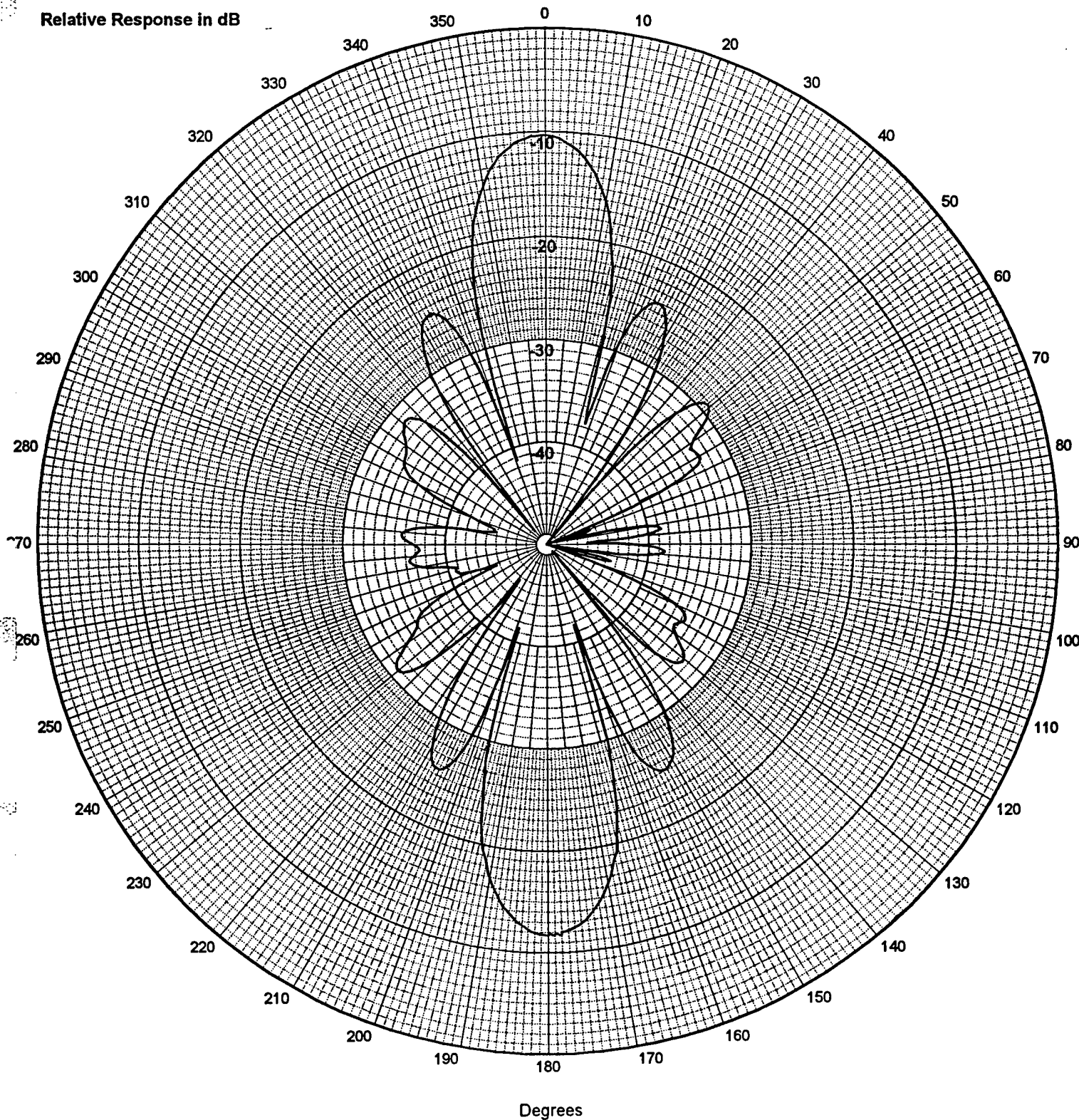
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



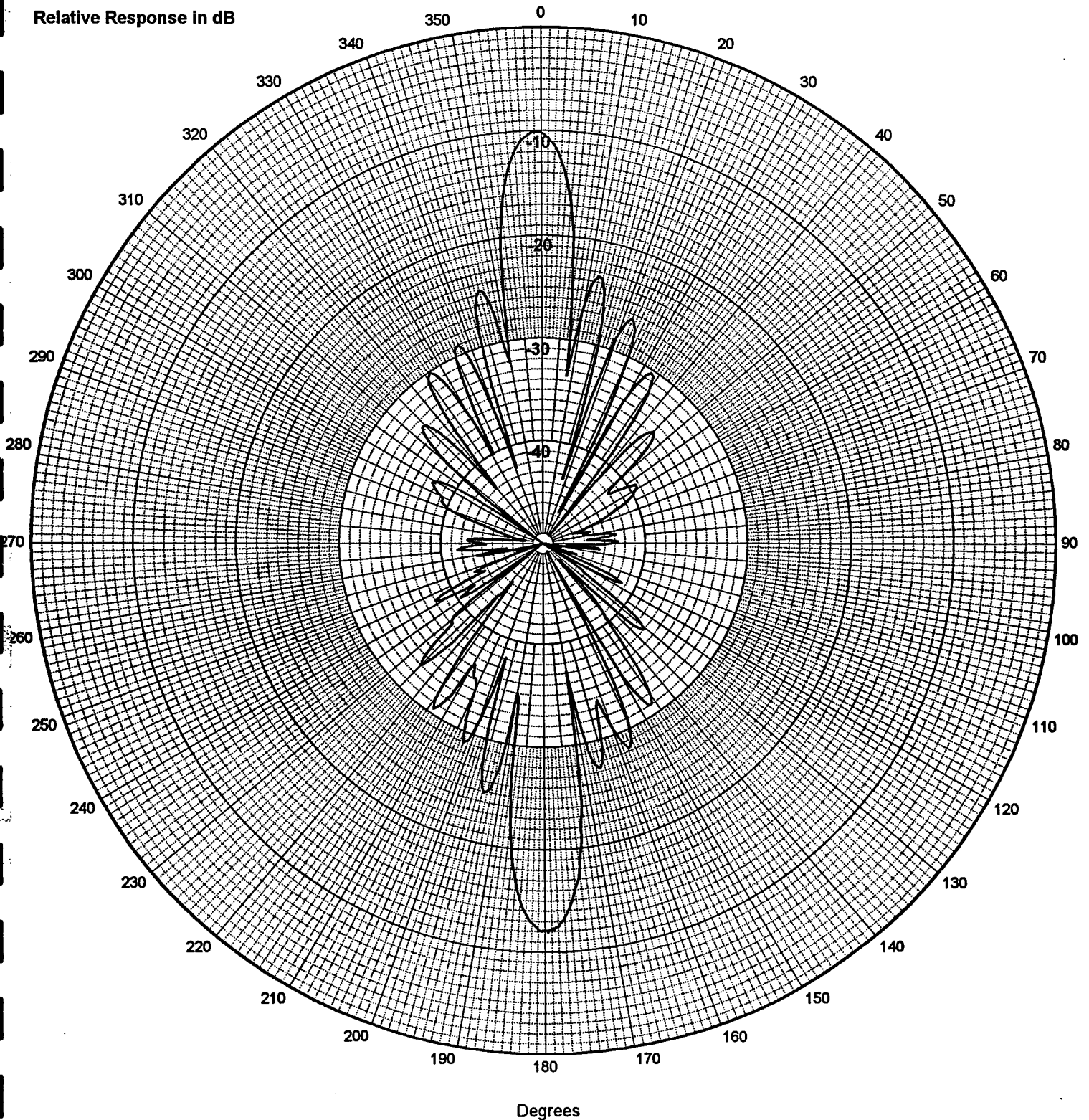
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0727-177  
ANECHOIC TANK FACILITY  
JAN 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-11P4  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



## FREE-FIELD VOLTAGE SENSITIVITY

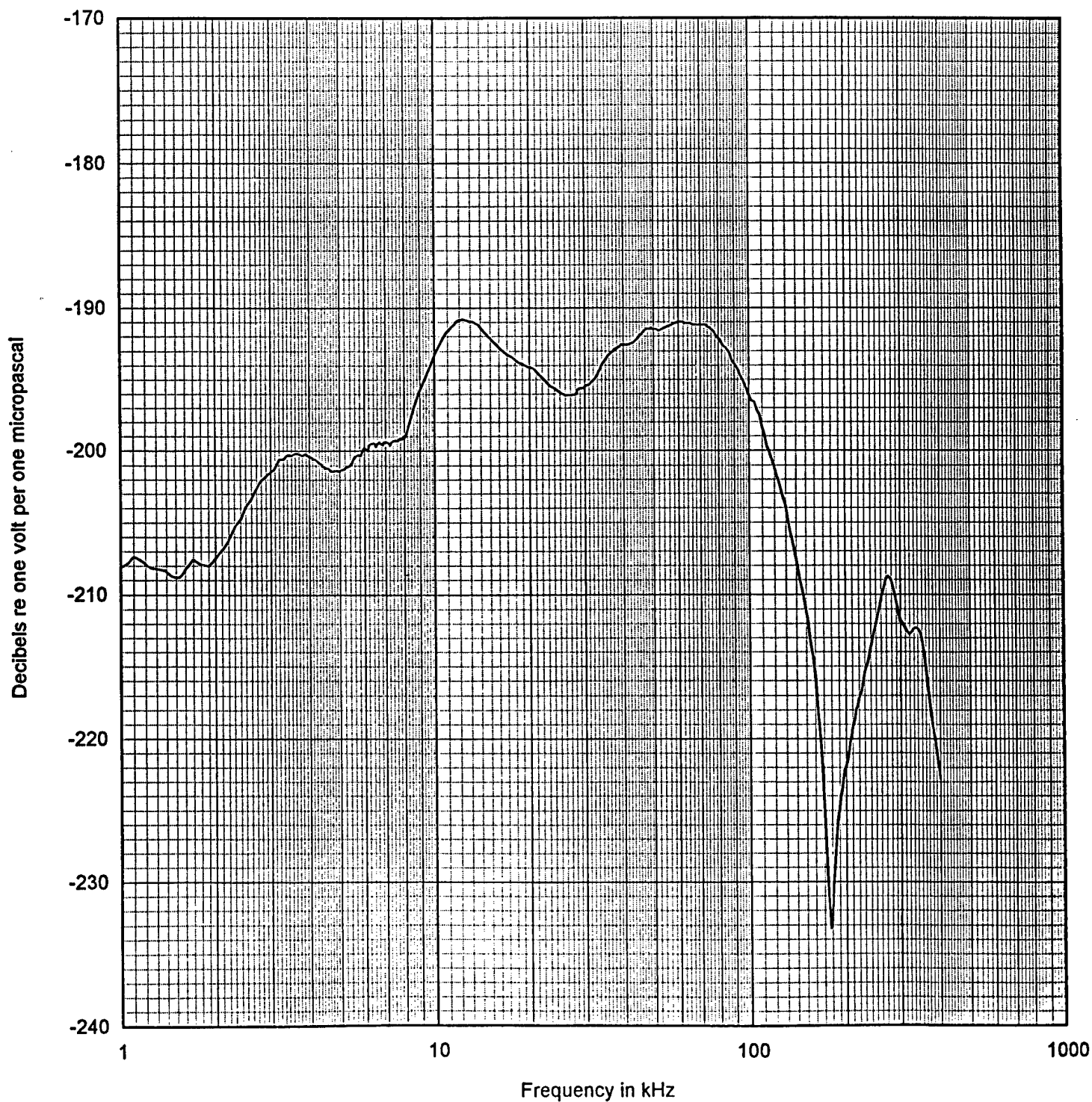
Piezocomposite Transducer Serial 2D-1

Open-circuit voltage measured at end of 15.0 -m cable; Unbalanced

Water Temp: 18° C

Test Depth 200 - 400 kHz: 0.6 m ( 5.8 kPa )

Test Depth 1 - 200 kHz: 3.9 m ( 38 kPa )





## TRANSMITTING VOLTAGE RESPONSE

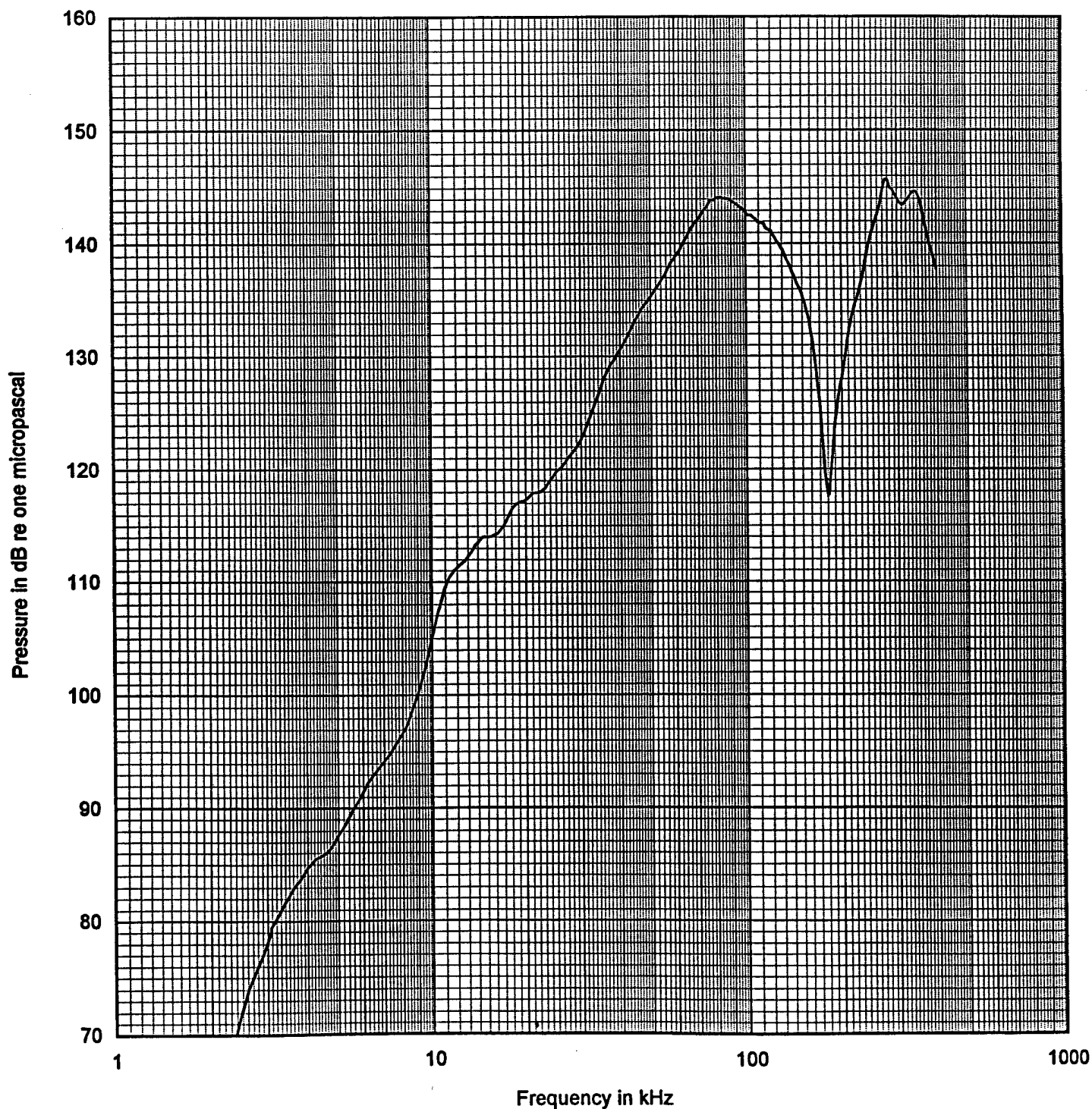
Piezocomposite Transducer Serial 2D-1

Pressure measured at one meter per volt applied at end of 15.0 -m cable; Unbalanced

Water Temp: 18° C

Test Depth 200 - 400 kHz: 0.6 m ( 5.8 kPa )

Test Depth 1 - 200 kHz: 3.9 m ( 38 kPa )





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 2D-1

Depth: 3.9 m (38 kPa)

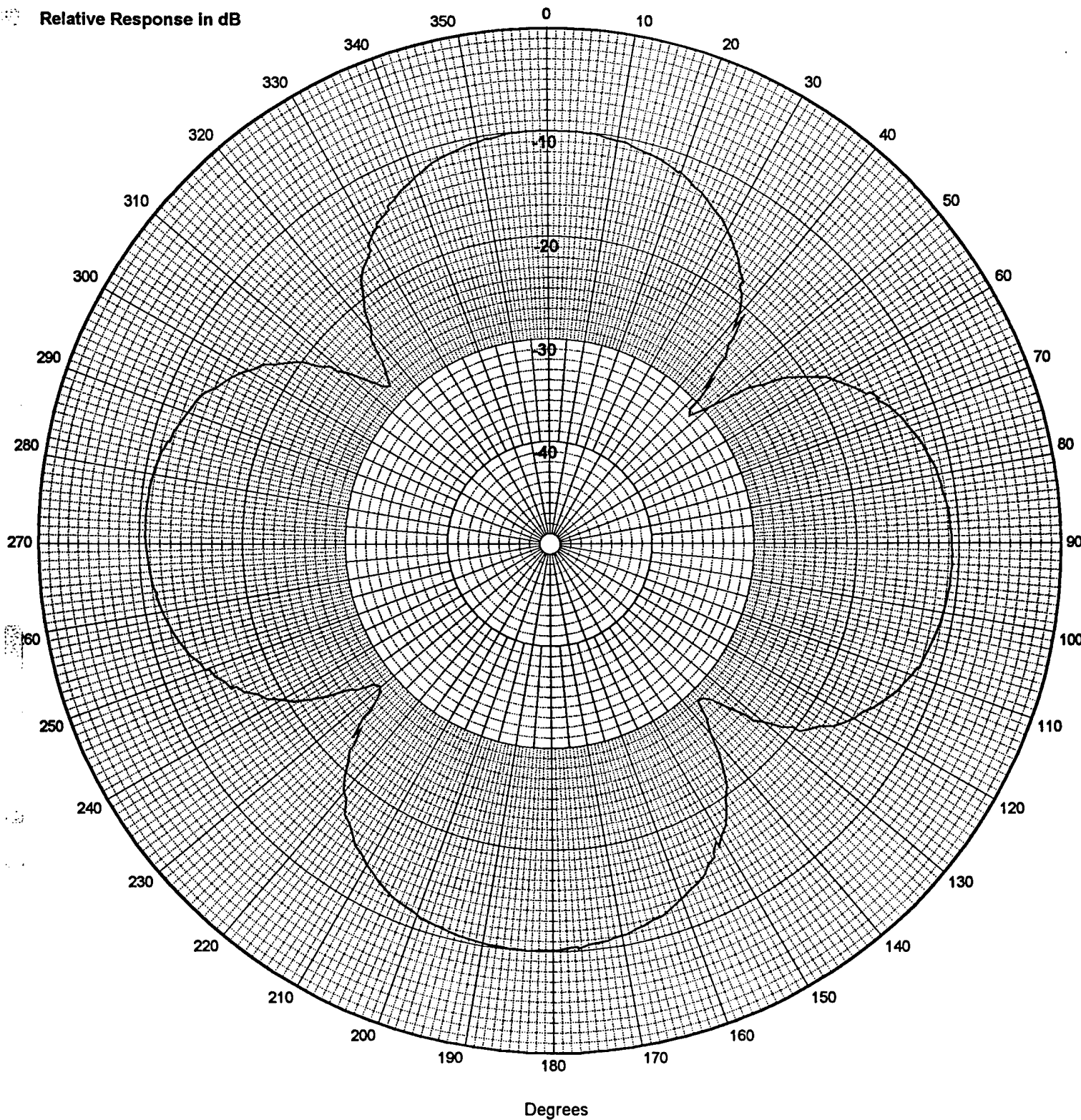
Water Temp: 15° C

Receive

XY Plane

10 kHz

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0727-181  
LAKE FACILITY  
FEB 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 2D-1

Depth: 3.9 m (38 kPa)

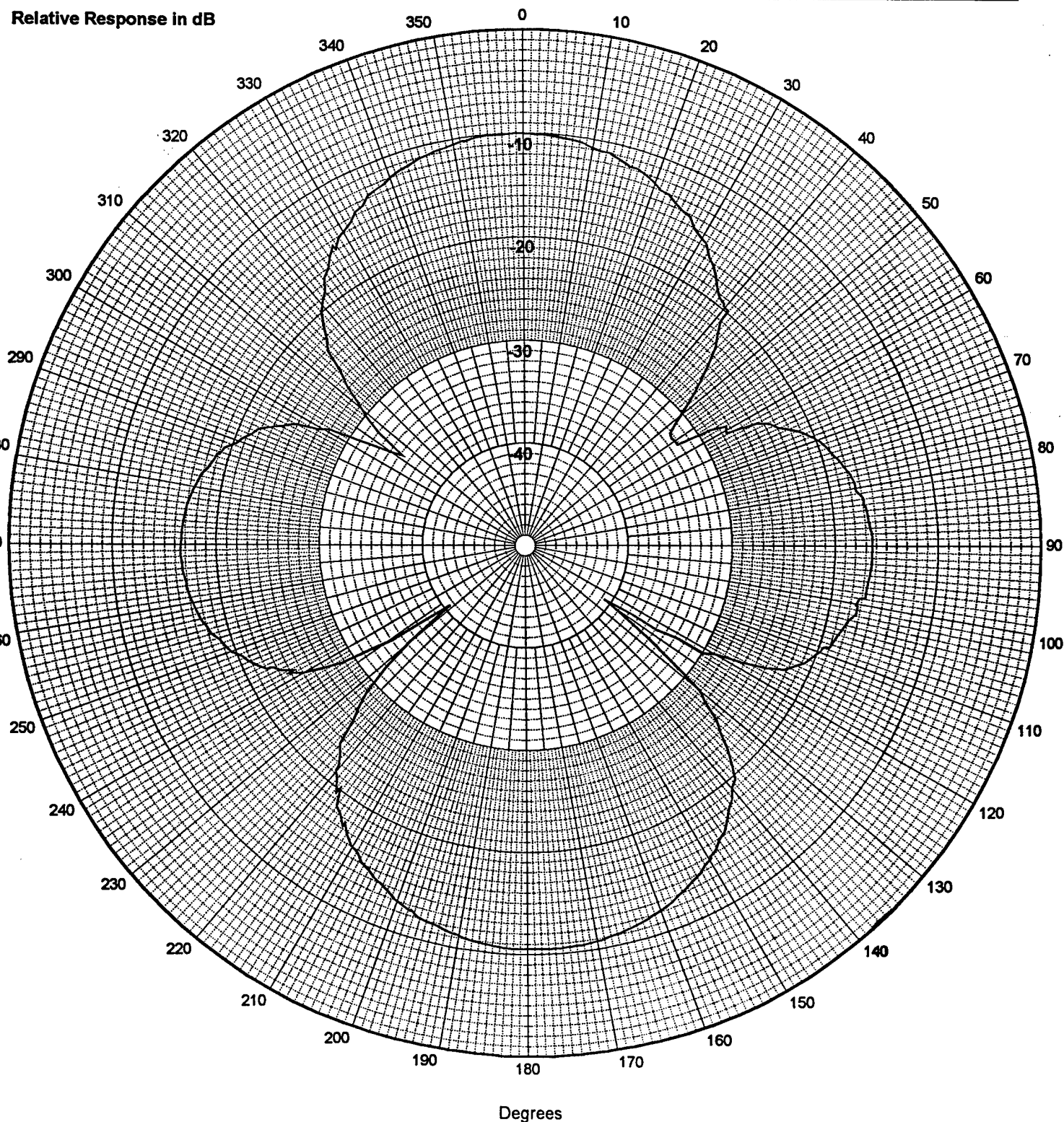
Water Temp: 15° C

Receive

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 2D-1

Depth: 3.9 m (38 kPa)

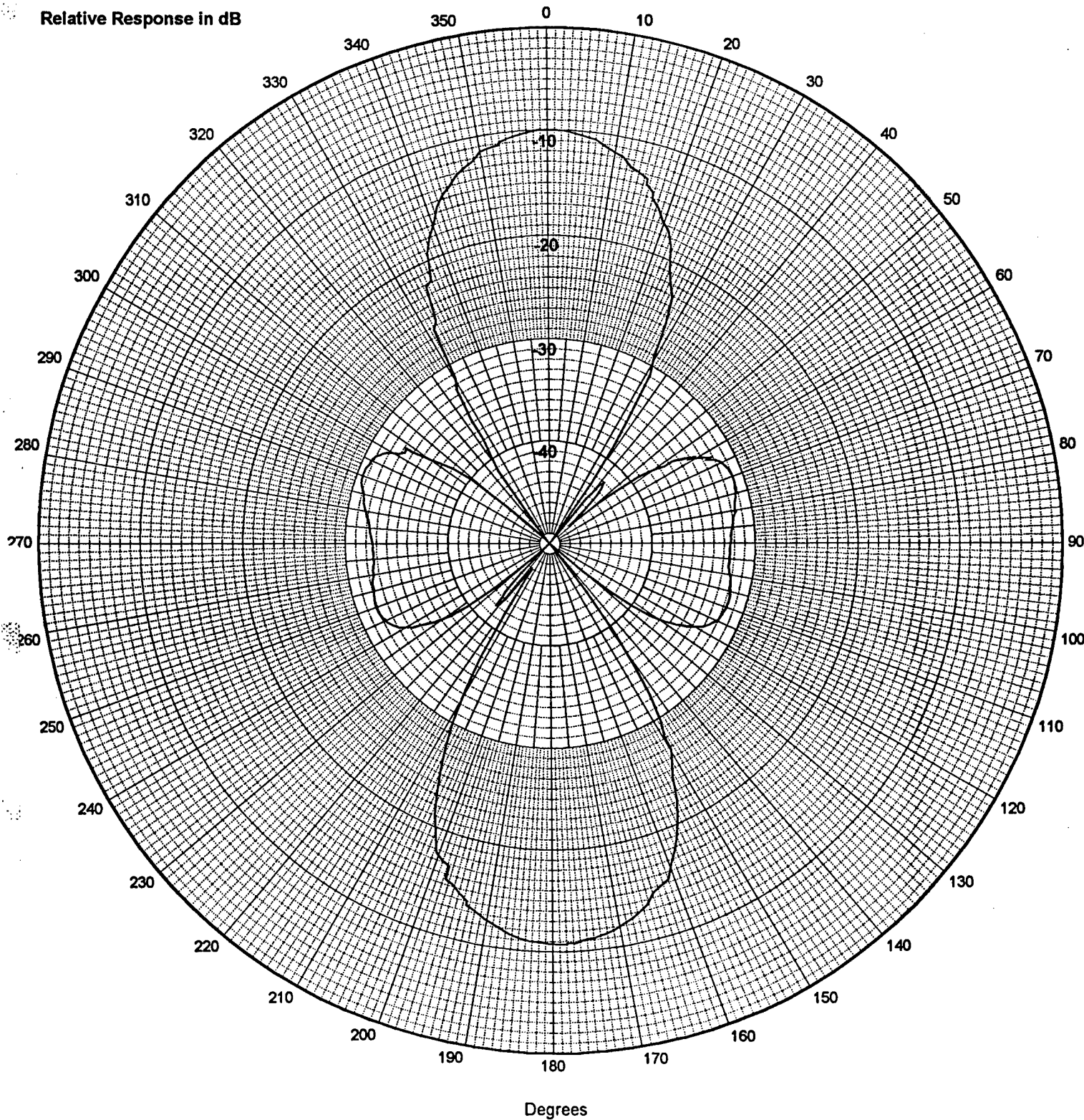
Water Temp: 15° C

Receive

XY Plane

50 kHz

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0727-183  
LAKE FACILITY  
FEB 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 2D-1

Depth: 3.9 m (38 kPa)

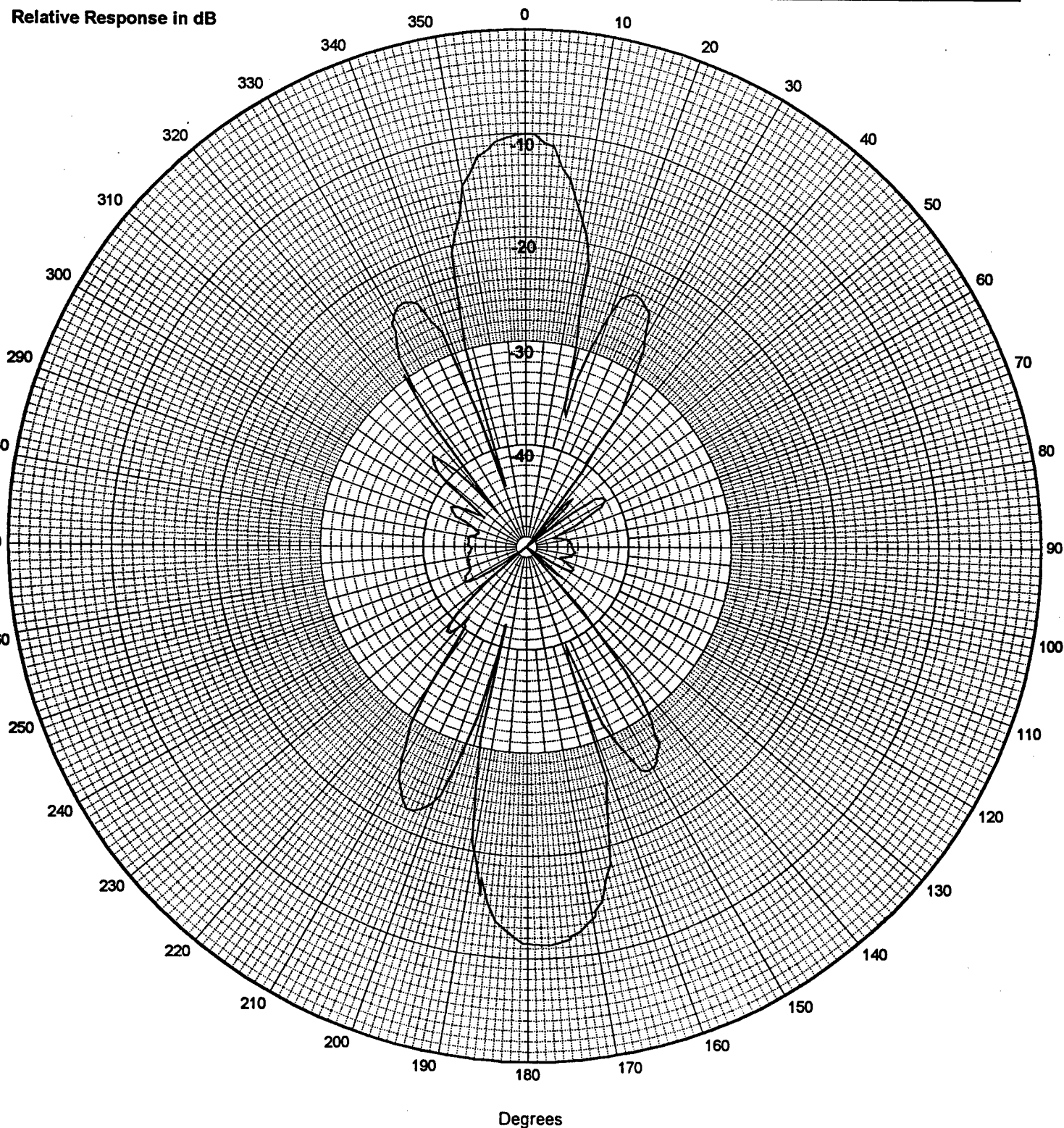
Water Temp: 15° C

Receive

XY Plane

100 kHz

Relative Response in dB





## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-48

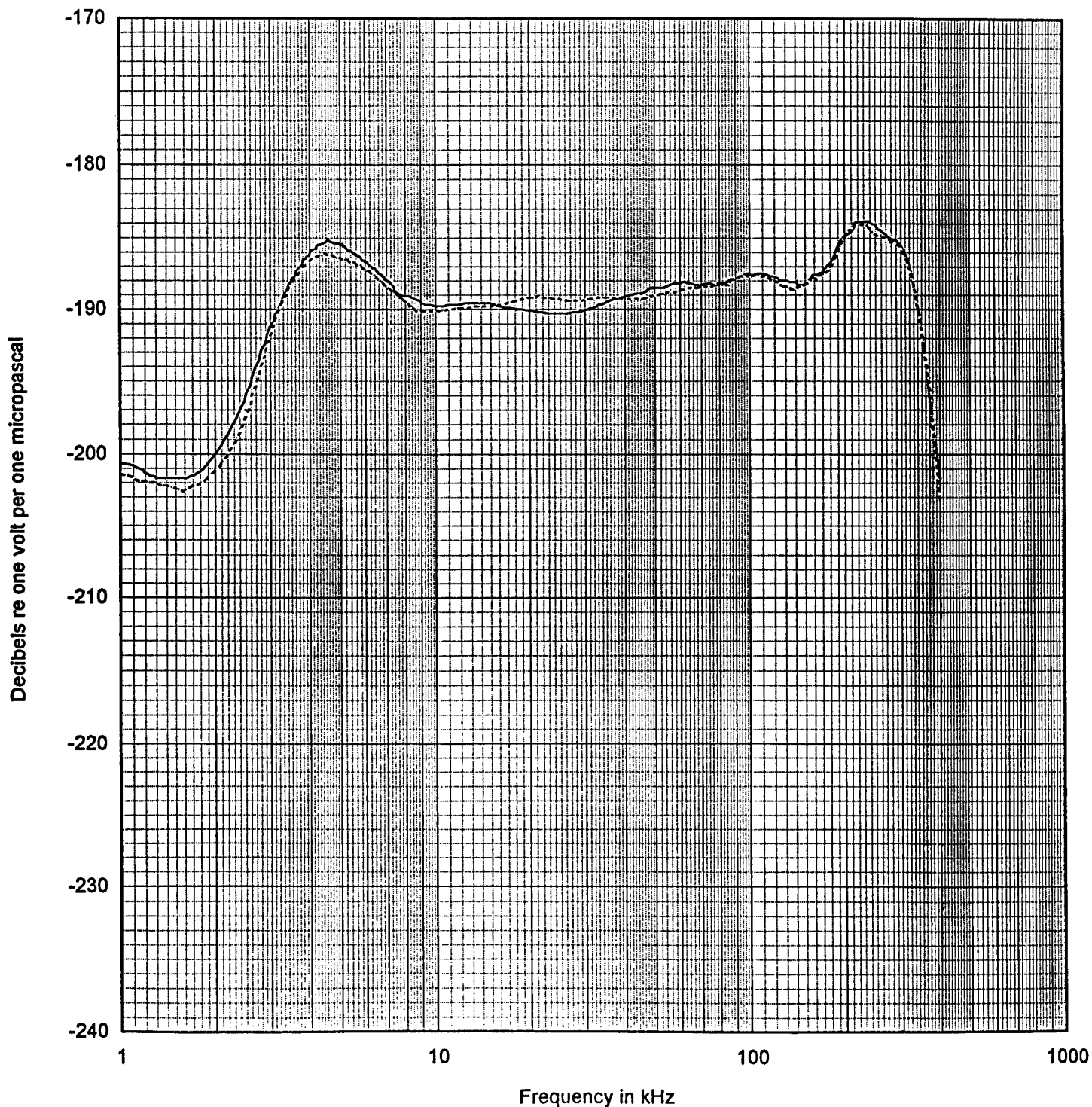
Open-circuit voltage measured at end of 30.0 -m cable; Unbalanced

Water Temp: 18° C

Test Depth 200 - 400 kHz: 0.6 m ( 5.8 kPa )

Test Depth 1 - 200 kHz: 3.9 m ( 38 kPa )

— Pre-Shock Measurement  
- - - - - Post-Shock Measurement





## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-48

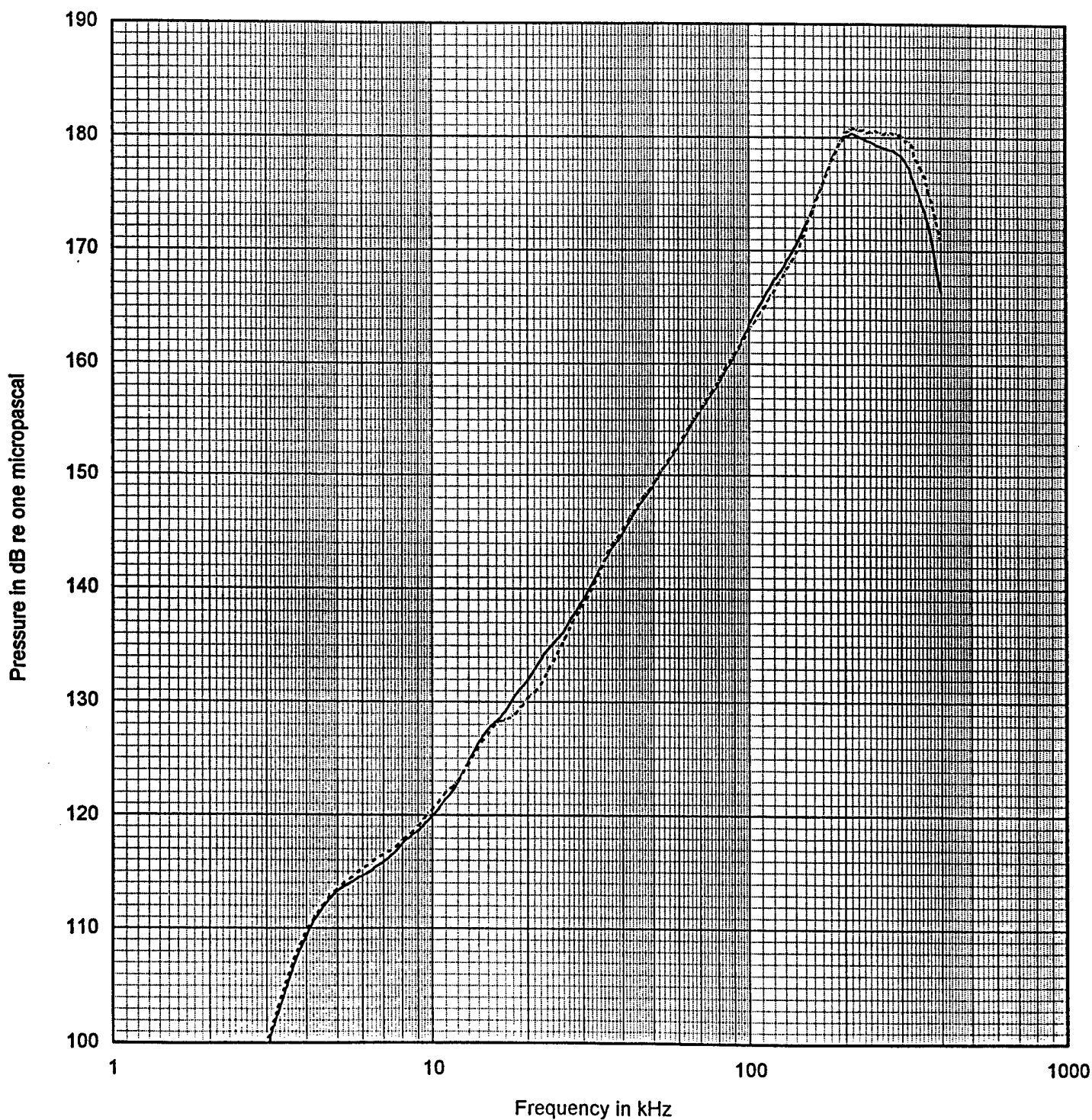
Pressure measured at one meter per volt applied at end of 30.0 -m cable; Unbalanced

Water Temp: 18° C

Test Depth 200 - 400 kHz: 0.6 m ( 5.8 kPa )

Test Depth 1 - 200 kHz: 3.9 m ( 38 kPa )

— Pre-Shock Measurement  
- - - Post-Shock Measurement



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Depth: 3.9 m (38 kPa)

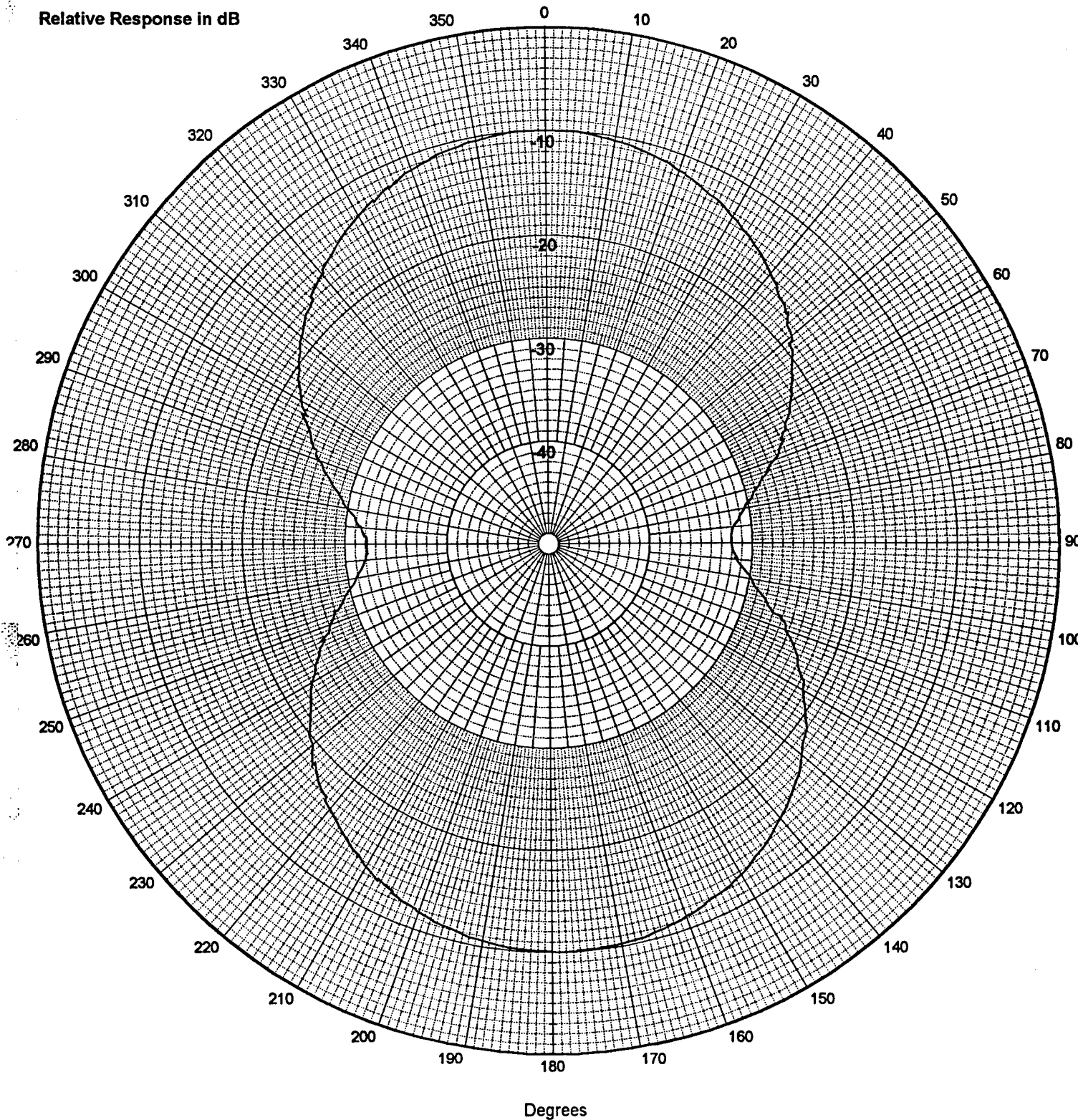
Water Temp: 15° C

Receive, Pre-Shock

XY Plane

10 kHz

Relative Response in dB



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0727-187  
LAKE FACILITY  
FEB 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Depth: 3.9 m (38 kPa)

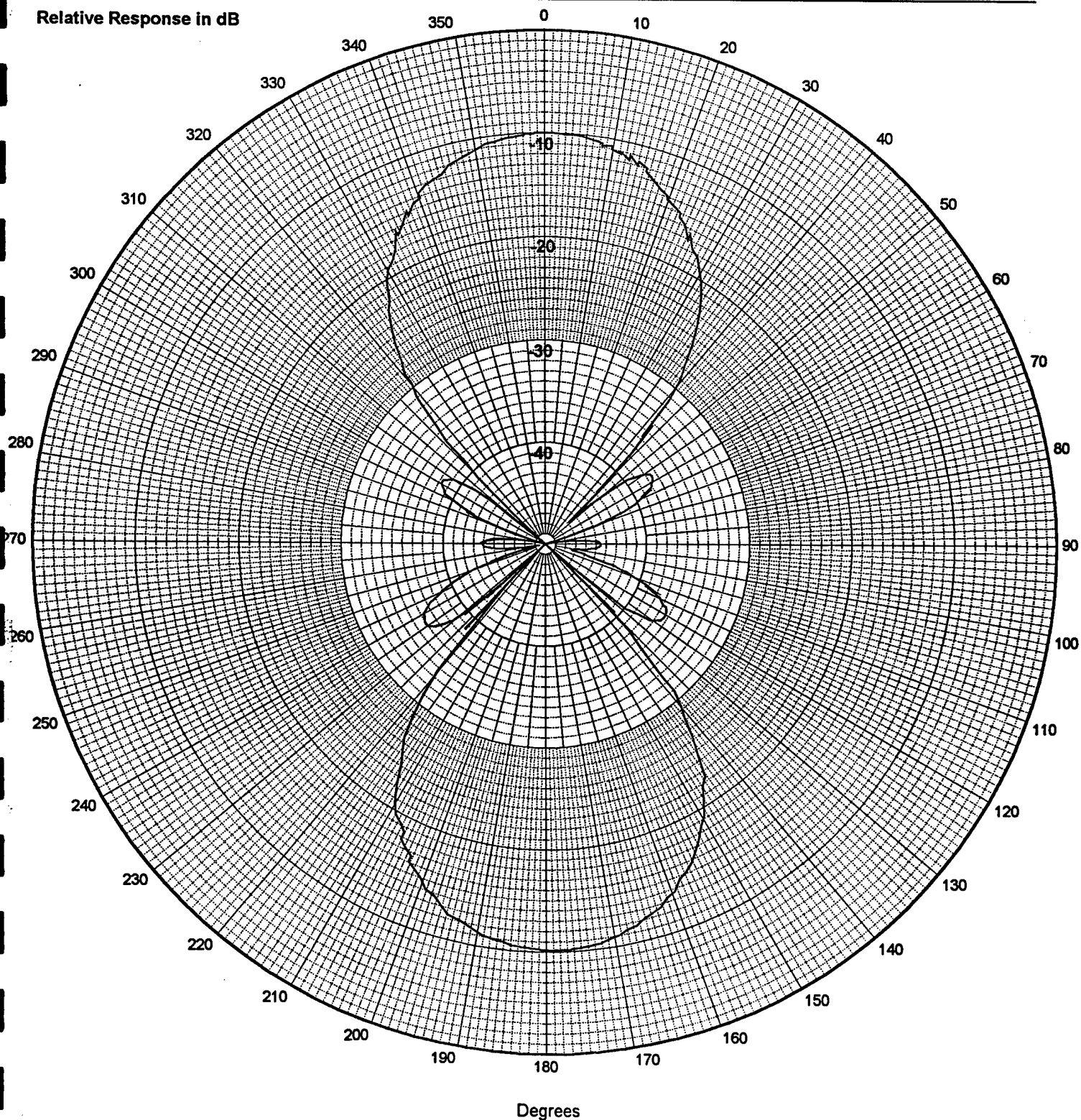
Water Temp: 15° C

Receive, Pre-Shock

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Depth: 3.9 m (38 kPa)

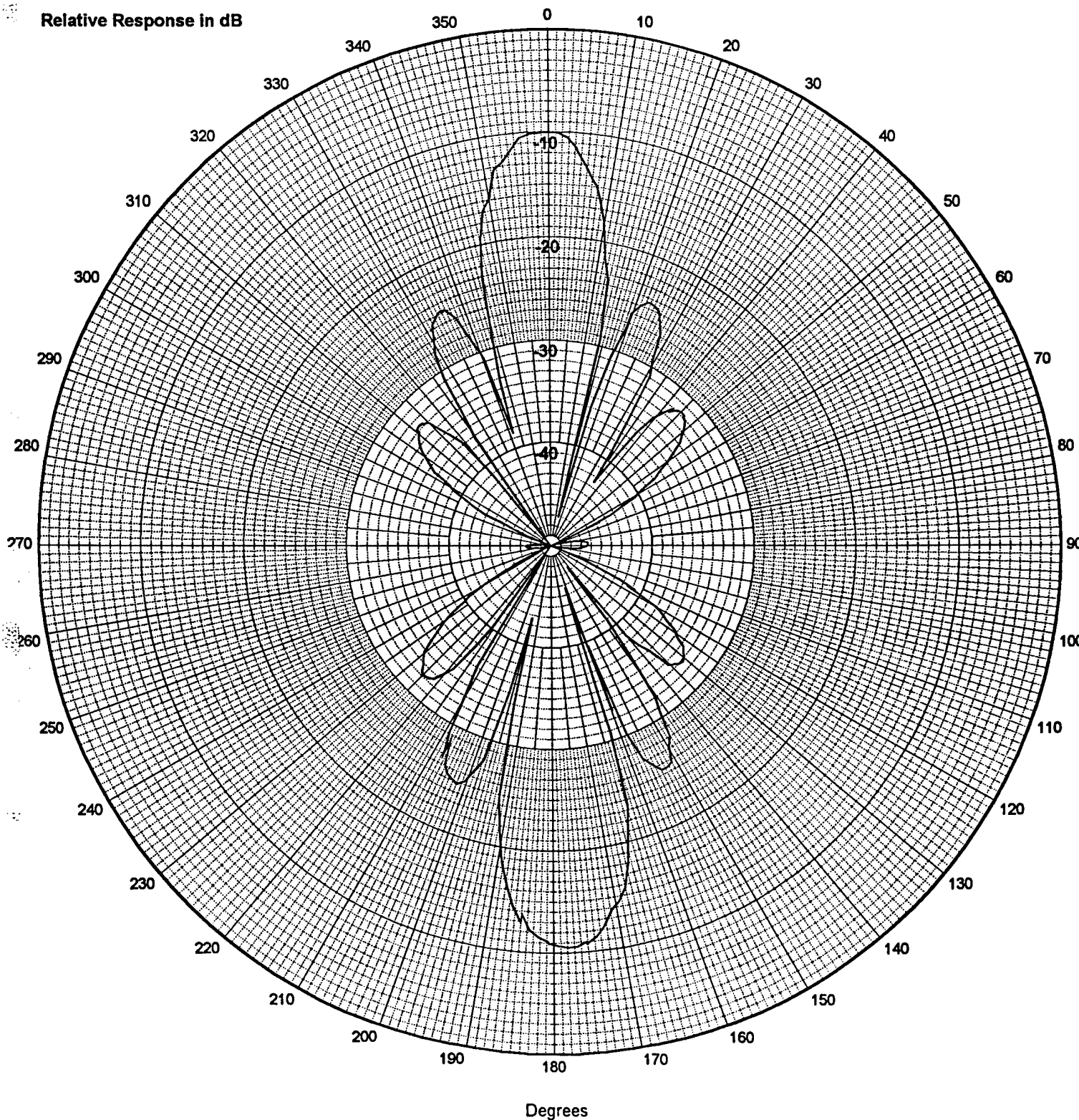
Water Temp: 15° C

Receive, Pre-Shock

XY Plane

50 kHz

Relative Response in dB





NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0727-189  
LAKE FACILITY  
FEB 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-48

Depth: 3.9 m (38 kPa)

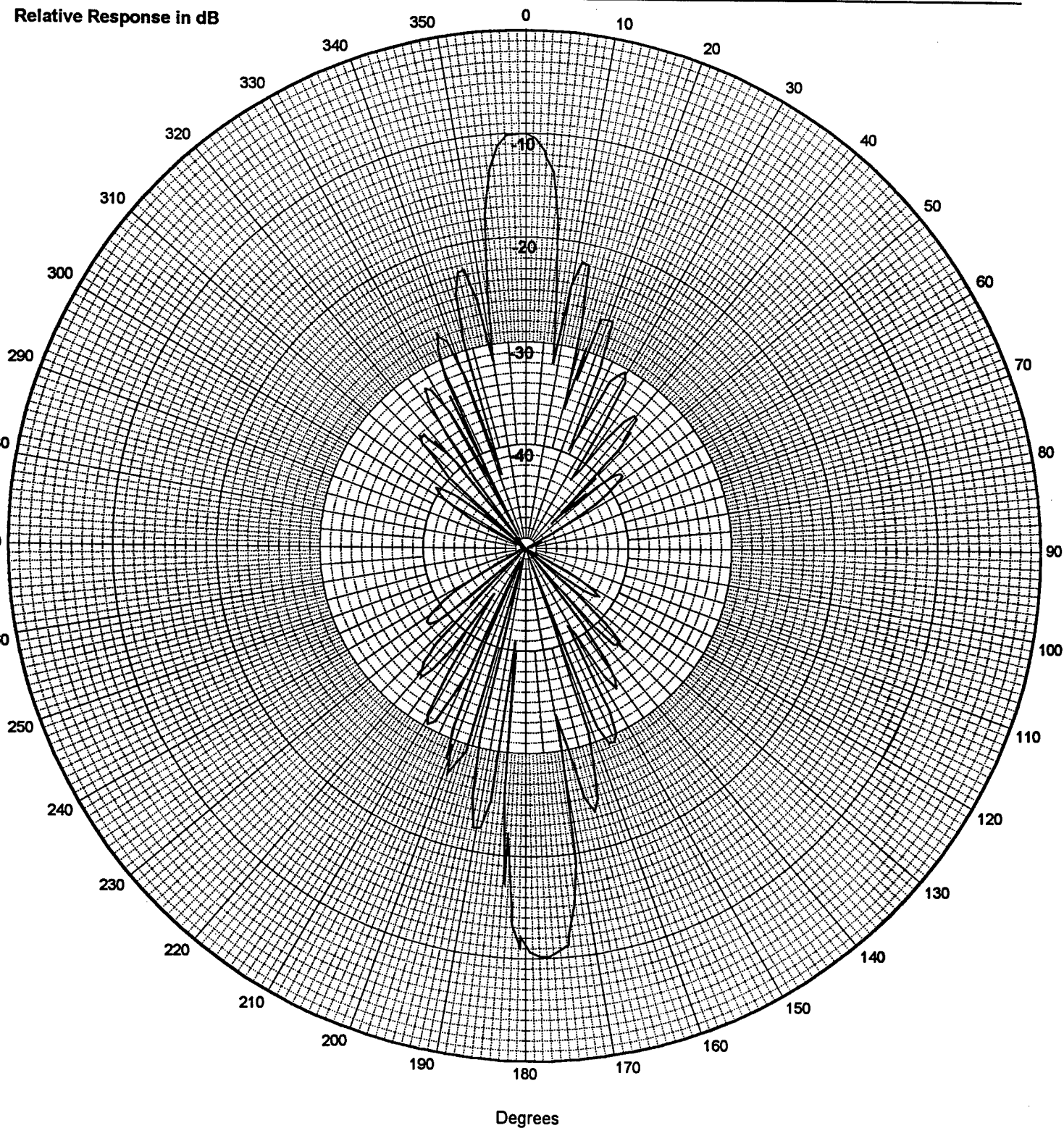
Water Temp: 15° C

Receive, Pre-Shock

XY Plane

100 kHz

Relative Response in dB





30°  
330°

20°  
340°

10°  
350°

350°  
10°

340°  
20°

330°  
30°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

USRD NO: 0727-190  
FACILITY: LAKE  
DATE: FEB 1996  
WATER TEMP: 15°C  
DEPTH: 3.9 m  
(38 kPa)

Relative Response in dB

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Receive, Post Shock  
XY Plane  
10 kHz

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

30°  
330°

20°  
340°

10°  
350°

0

350°  
10°

340°  
20°

330°  
30°

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

Relative Response in dB

USRD NO: 0727-191  
FACILITY: LAKE  
DATE: FEB 1996  
WATER TEMP: 15°C  
DEPTH: 3.9 m  
(38 kPa)

40°  
20°  
50°  
310°  
60°  
300°  
70°  
290°  
80°  
280°  
90°  
270°  
100°  
260°  
110°  
250°  
120°  
240°  
130°  
230°  
140°  
220°

320°  
40°  
310°  
50°  
300°  
60°  
290°  
70°  
280°  
80°  
270°  
90°  
260°  
100°  
250°  
110°  
120°  
130°  
140°

NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P.O. BOX 568337, ORLANDO, FL 32856-8337

DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Receive, Post Shock  
XY Plane  
20 kHz

30°  
330°

20°  
340°

10°  
350°

0°

350°  
10°

340°  
20°

330°  
30°

NOTE: ALLOW 10.2 dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK OMNIDIRECTIONALITY.

USRD NO: 0727-192  
FACILITY: LAKE  
DATE: FEB 1996  
WATER TEMP: 15°C  
DEPTH: 3.9 m  
(38 kPa)

Relative Response in dB

50°  
310°

60°  
300°

70°  
290°

80°  
280°

90°  
270°

100°  
260°

110°  
250°

120°  
240°

130°  
230°

140°  
220°

150°  
210°

160°  
200°

170°  
190°

180°

190°

200°

210°

220°

230°

240°

250°

260°

270°

280°

290°

300°

310°

320°

330°

340°

350°

360°

370°

380°

390°

400°

410°

420°

430°

440°

450°

460°

470°

480°

490°

500°

510°

520°

530°

540°

550°

560°

570°

580°

590°

600°

610°

620°

630°

640°

650°

660°

670°

680°

690°

700°

710°

720°

730°

740°

750°

760°

770°

780°

790°

800°

810°

820°

830°

840°

850°

860°

870°

880°

890°

900°

910°

920°

930°

940°

950°

960°

970°

980°

990°

1000°

1010°

1020°

1030°

1040°

1050°

1060°

1070°

1080°

1090°

1100°

1110°

1120°

1130°

1140°

1150°

1160°

1170°

1180°

1190°

1200°

1210°

1220°

1230°

1240°

1250°

1260°

1270°

1280°

1290°

1300°

1310°

1320°

1330°

1340°

1350°

1360°

1370°

1380°

1390°

1400°

1410°

1420°

1430°

1440°

1450°

1460°

1470°

1480°

1490°

1500°

1510°

1520°

1530°

1540°

1550°

1560°

1570°

1580°

1590°

1600°

1610°

1620°

1630°

1640°

1650°

1660°

1670°

1680°

1690°

1700°

1710°

1720°

1730°

1740°

1750°

1760°

1770°

1780°

1790°

1800°

1810°

1820°

1830°

1840°

1850°

1860°

1870°

1880°

1890°

1900°

1910°

1920°

1930°

1940°

1950°

1960°

1970°

1980°

1990°

2000°

2010°

2020°

2030°

2040°

2050°

2060°

2070°

2080°

2090°

2100°

2110°

2120°

2130°

2140°

2150°

2160°

2170°

2180°

2190°

2200°

2210°

2220°

2230°

2240°

2250°

2260°

2270°

2280°

2290°

2300°

2310°

2320°

2330°

2340°

2350°

2360°

2370°

2380°

2390°

2400°

2410°

2420°

2430°

2440°

2450°

2460°

2470°

2480°

2490°

2500°

2510°

2520°

2530°

2540°

2550°

2560°

2570°

2580°

2590°

2600°

2610°

2620°

2630°

2640°

2650°

2660°

2670°

2680°

2690°

2700°

2710°

2720°

2730°

2740°

2750°

2760°

2770°

2780°

2790°

2800°

2810°

2820°

2830°

2840°

2850°

2860°

2870°

2880°

2890°

2900°

2910°

2920°

2930°

2940°

2950°

2960°

2970°

2980°

2990°

3000°

3010°

3020°

3030°

3040°

3050°

3060°

3070°

3080°

3090°

3100°

3110°

3120°

3130°

3140°

3150°

3160°

3170°

3180°

3190°

3200°

3210°

3220°

3230°

3240°

3250°

3260°



30° 20° 10° 0 350° 340° 330°  
330° 340° 350° 10° 20° 30°

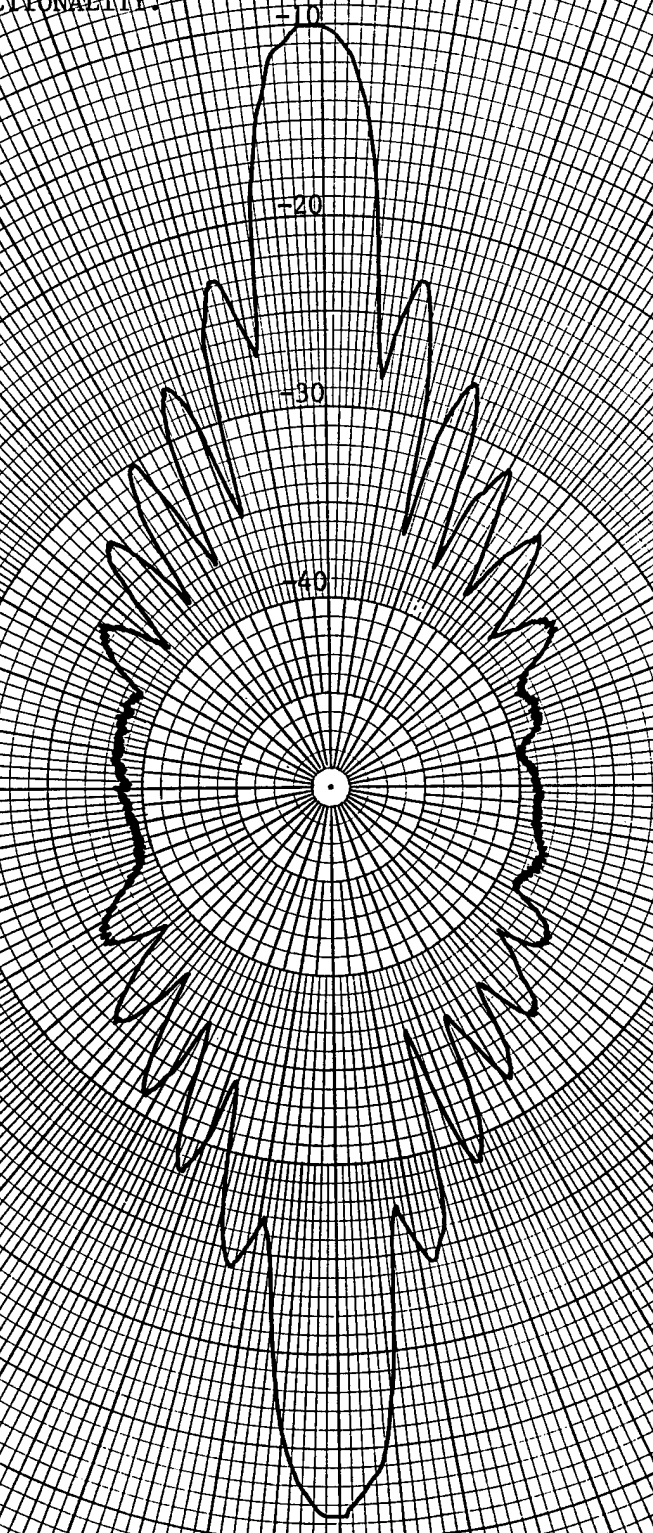
USRD NO: 0727-193  
FACILITY: LAKE  
DATE: FEB 1996  
WATER TEMP: 15°C  
DEPTH: 3.9 m  
(38 kPa)

NOTE: ALLOW  $\pm 0.2$  dB FOR PAPER  
STRETCH AND CENTERING. USE  
SCALE TO CHECK UNIDIRECTIONALITY.

Relative Response in dB

40° 320°  
50° 310°  
60° 300°  
70° 290°  
80° 280°  
90° 270°  
100° 260°  
110° 250°  
120° 240°  
130° 230°  
140° 220°

320° 40°  
310° 50°  
300° 60°  
290° 70°  
280° 80°  
270° 90°  
260° 100°  
250° 110°  
240° 120°  
230° 130°  
220° 140°



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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DIRECTIONAL RESPONSE  
Piezocomposite Transducer Serial 4-48  
Receive, Post Shock  
XY Plane  
100 kHz

## FREE-FIELD VOLTAGE SENSITIVITY

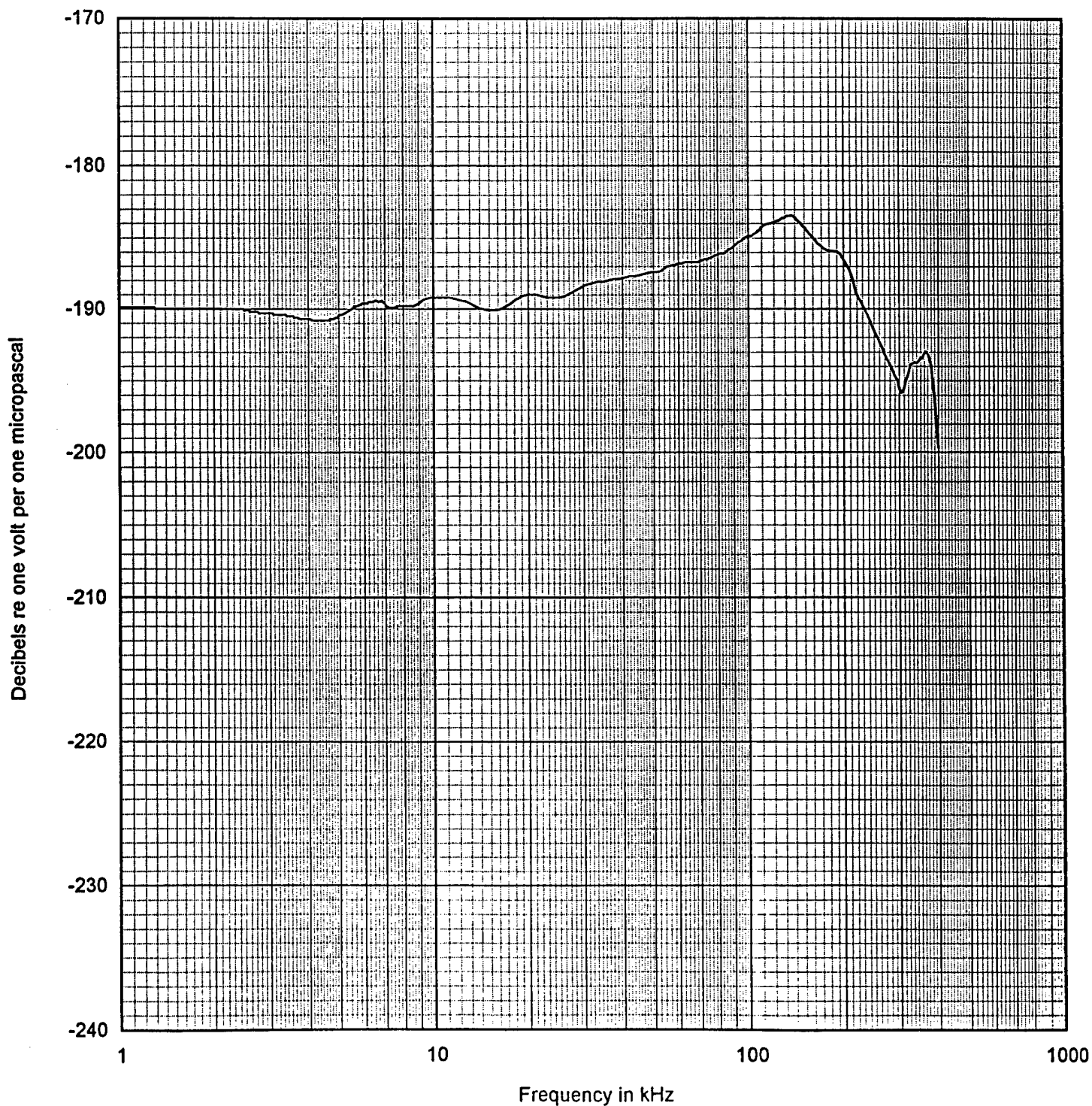
Piezocomposite Transducer Serial 4-50

Open-circuit voltage measured at end of 30.0 -m cable; Unbalanced

Water Temp: 18° C

Test Depth 200 - 400 kHz: 0.6 m ( 5.8 kPa )

Test Depth 1 - 200 kHz: 3.9 m ( 38 kPa )





## TRANSMITTING VOLTAGE RESPONSE

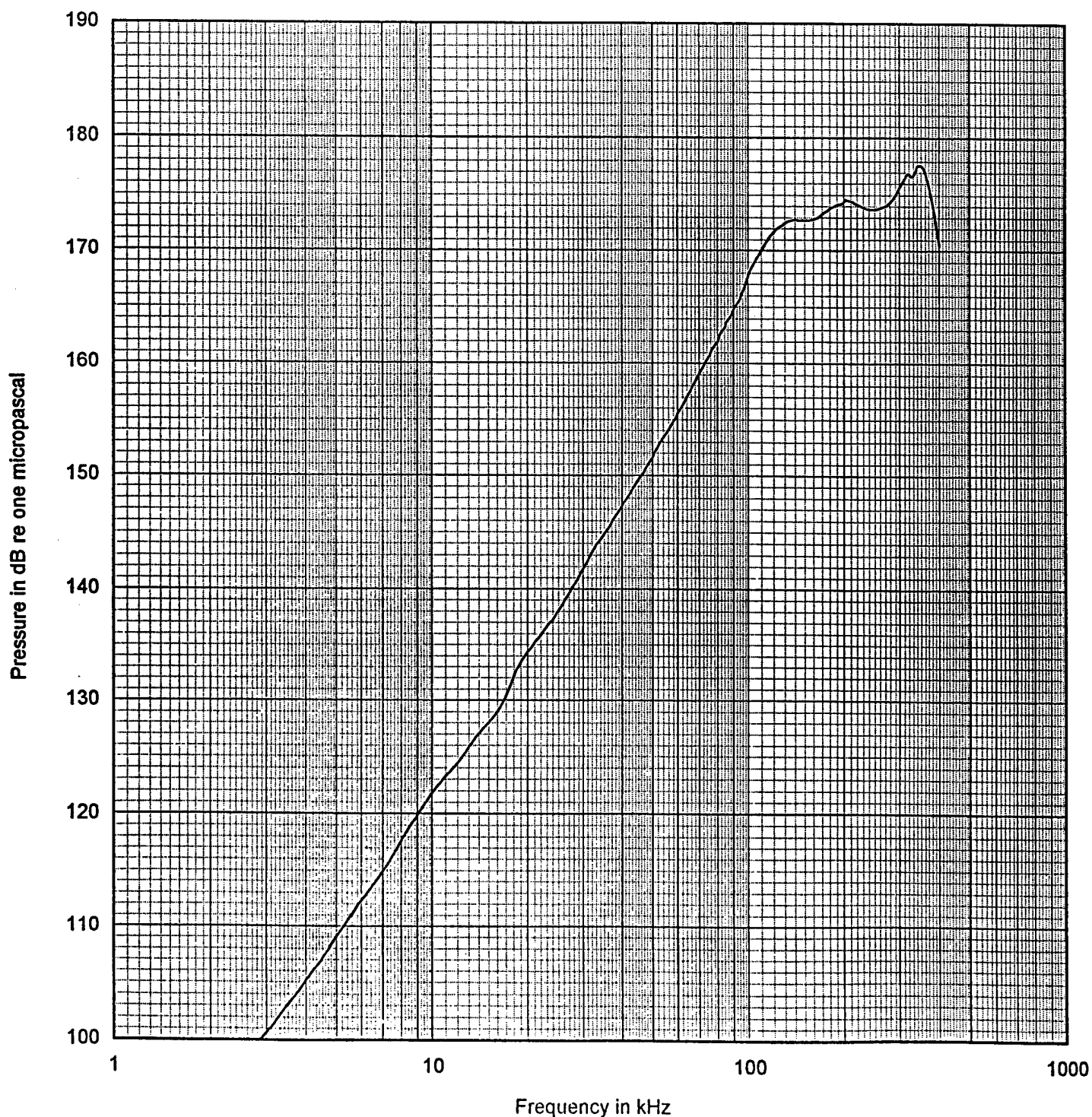
Piezocomposite Transducer Serial 4-50

Pressure measured at one meter per volt applied at end of 30.0 -m cable; Unbalanced

Water Temp: 18° C

Test Depth 200 - 400 kHz: 0.6 m ( 5.8 kPa )

Test Depth 1 - 200 kHz: 3.9 m ( 38 kPa )



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Depth: 3.9 m (38 kPa)

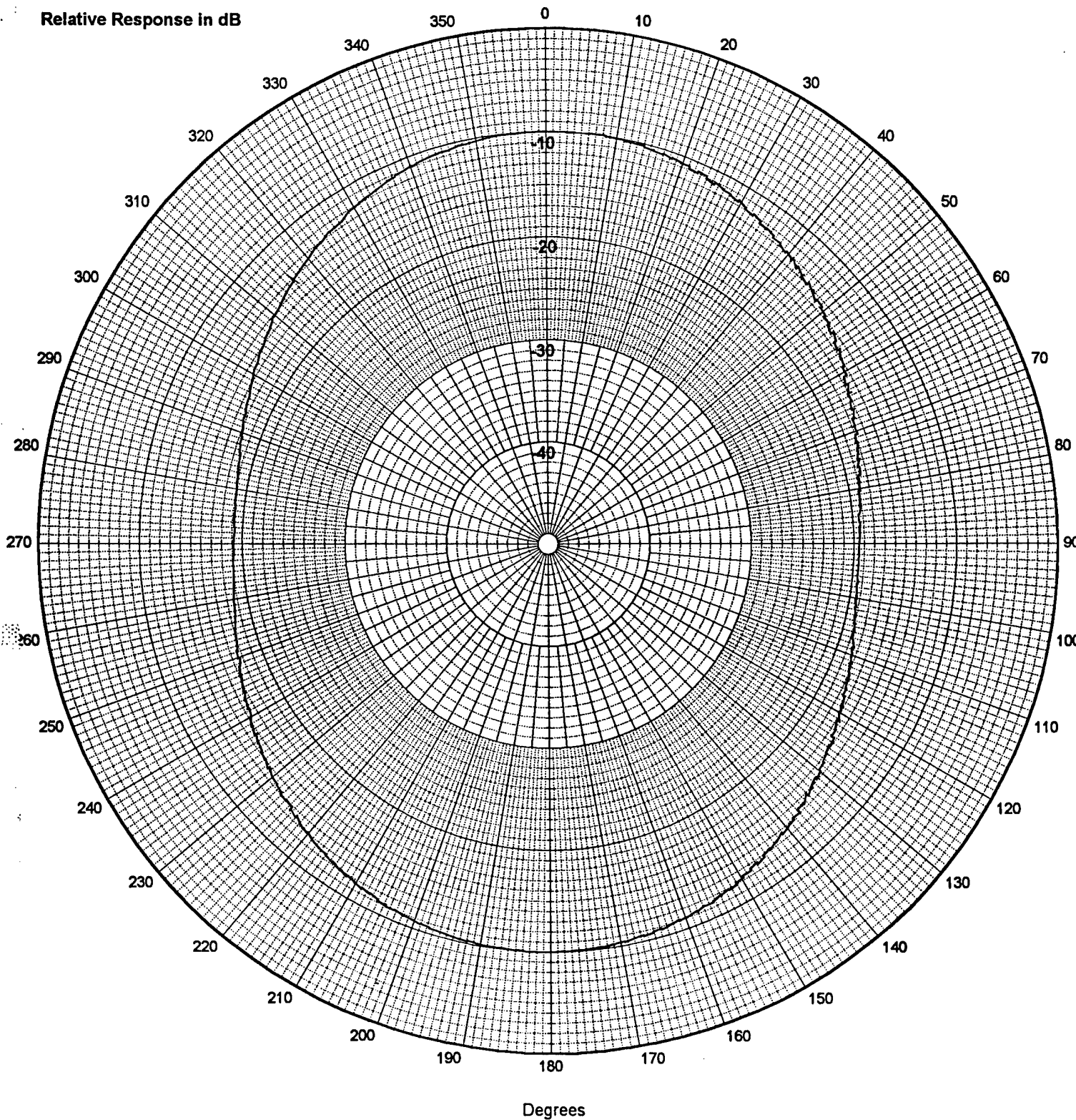
Water Temp: 15° C

Receive

XY Plane

10 kHz

Relative Response in dB



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USRD NO: 0727-197  
LAKE FACILITY  
FEB 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Depth: 3.9 m (38 kPa)

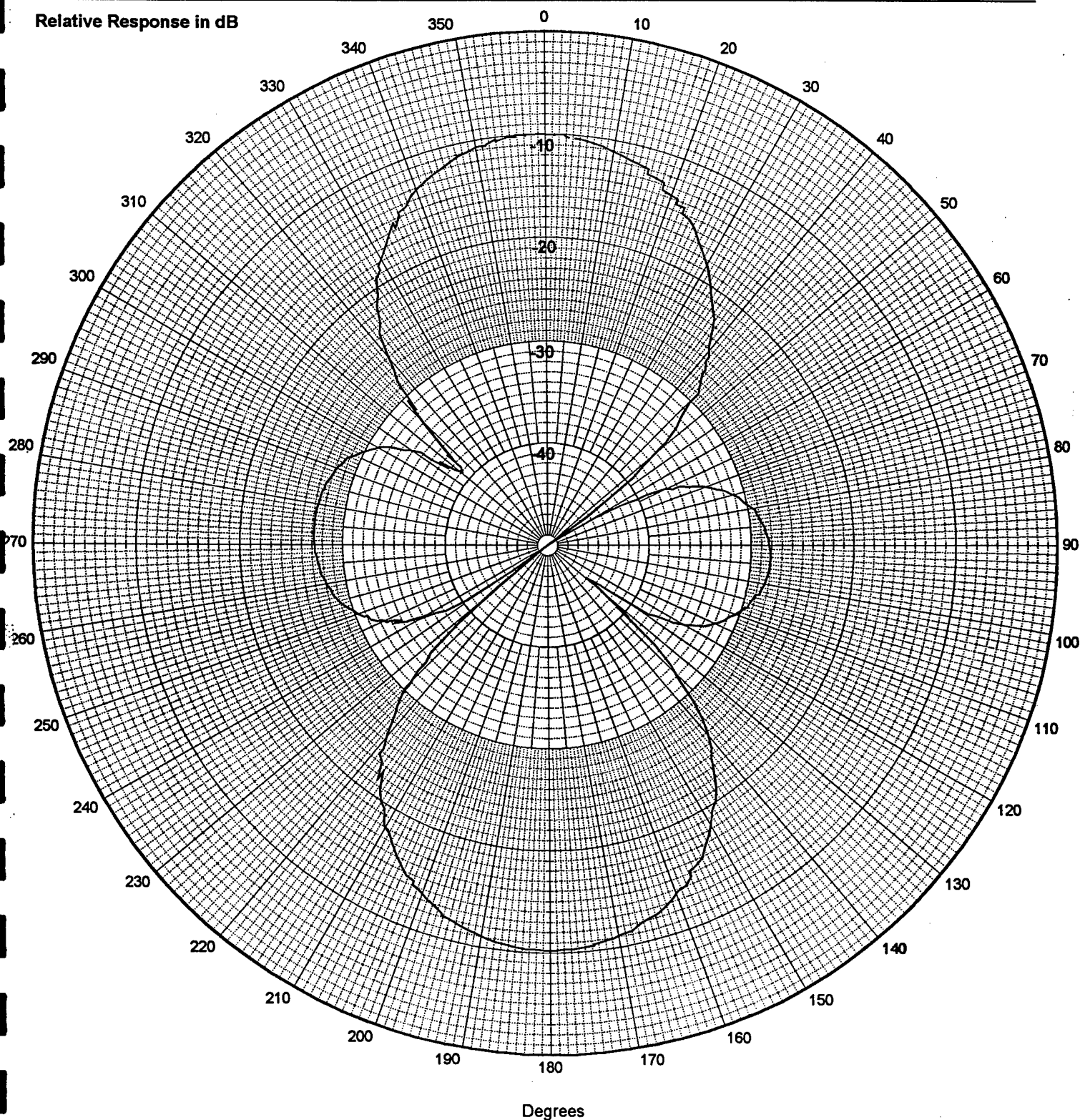
Water Temp: 15° C

Receive

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Depth: 3.9 m (38 kPa)

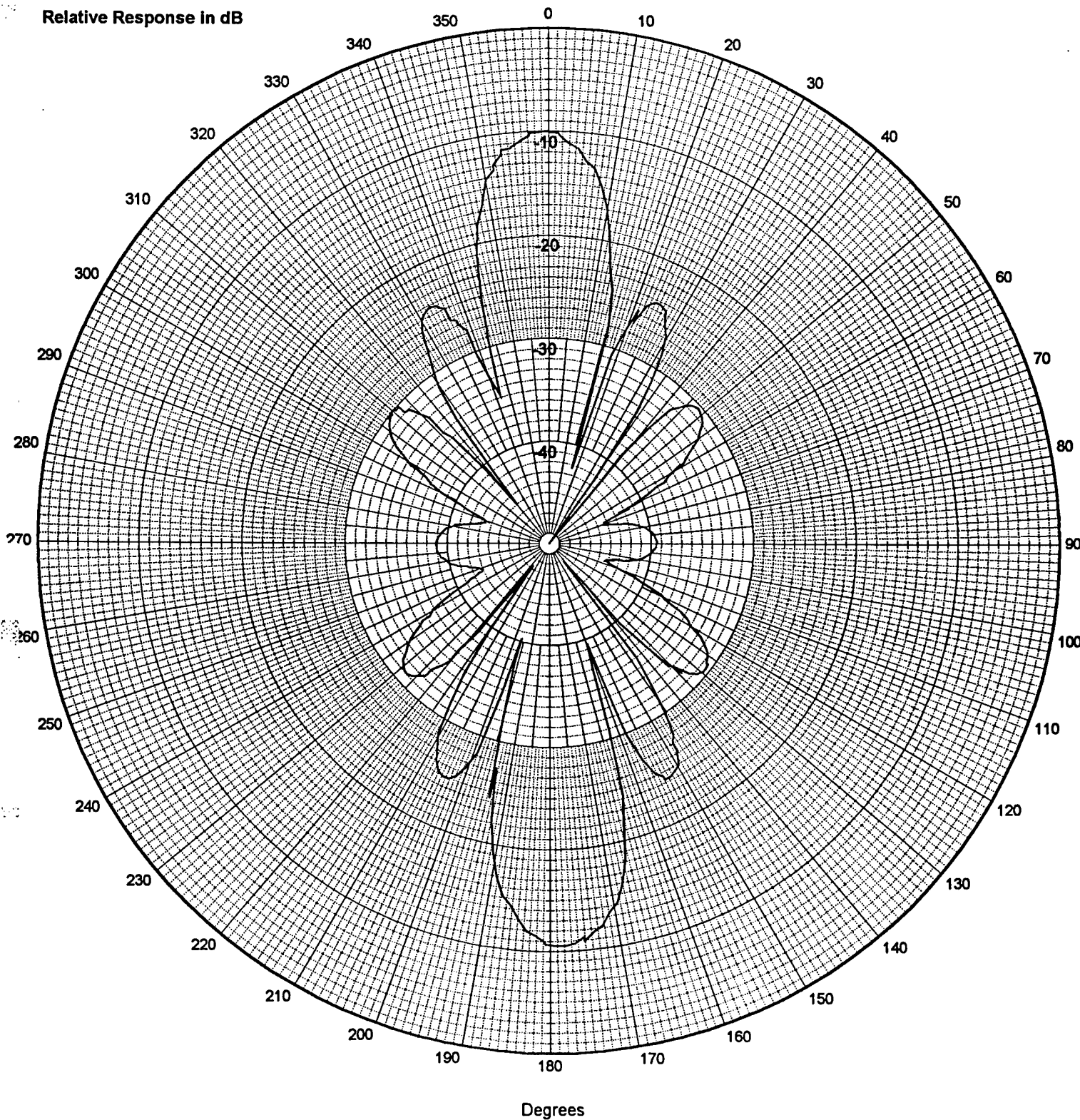
Water Temp: 15° C

Receive

XY Plane

50 kHz

Relative Response in dB





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USRD NO: 0727-199  
LAKE FACILITY  
FEB 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-50

Depth: 3.9 m (38 kPa)

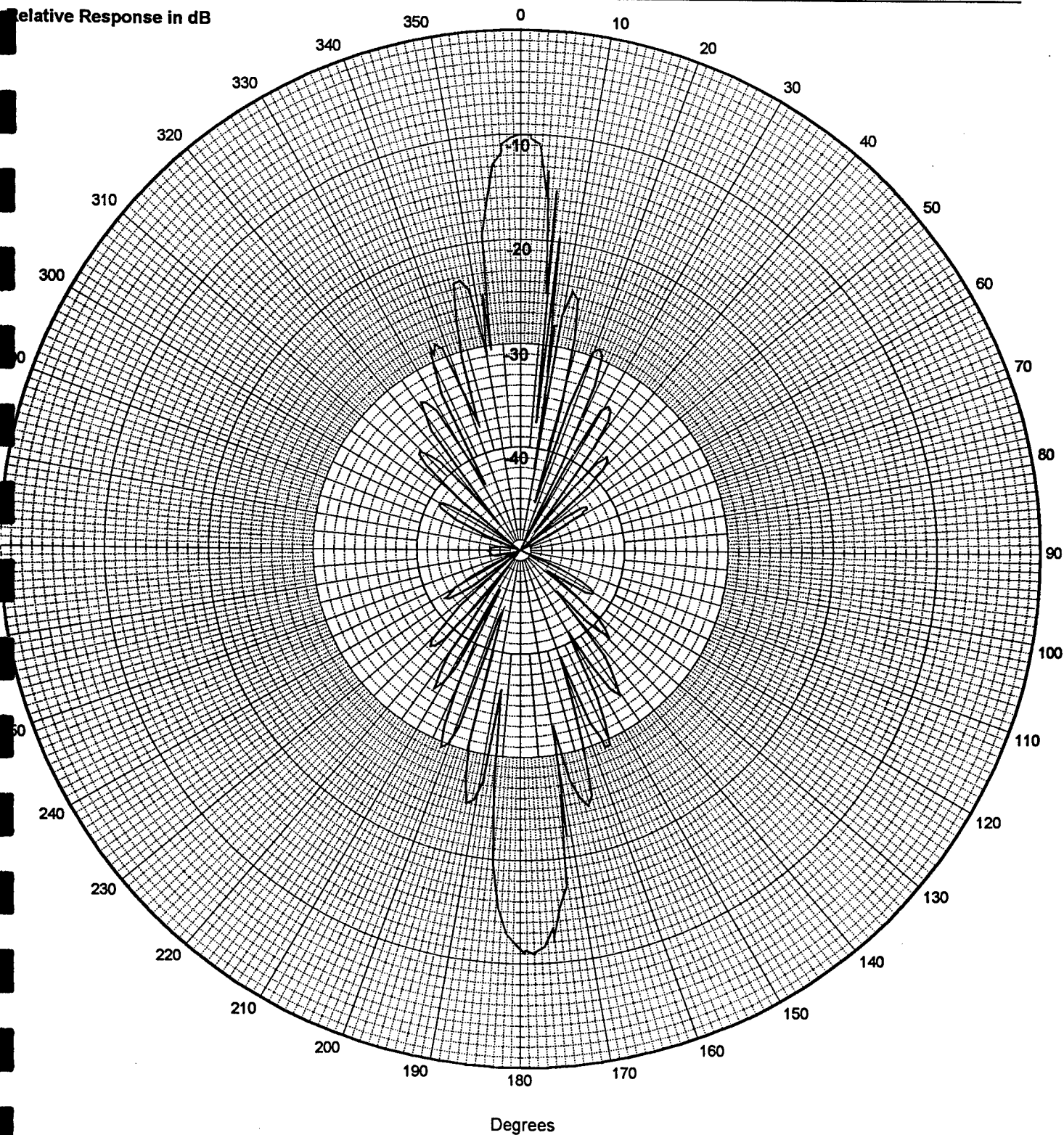
Water Temp: 15° C

Receive

Y Plane

100 kHz

Relative Response in dB



# Appendix E



# DEPARTMENT OF THE NAVY

NAVAL UNDERSEA WARFARE CENTER  
1176 HOWELL STREET  
NEWPORT RI 02841-1708



NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P O BOX 568337  
ORLANDO FL 32856-8337

IN REPLY REFER TO:

3965

Ser X72500-0779  
29 APR 1996

## USRD CALIBRATION MEMORANDUM NO. 0779

Subj: MEASUREMENTS ON PIEZOCOMPOSITE TRANSDUCERS SERIALS 4-44, 4-67, 4-70,  
AND 4K-1

Ref: (a) Fonecon, Mr. T. Howarth of NRL to Mr. R. Drake of NUWC-USRD,  
21 Mar 1996  
(b) NUWC-USRD Job Order No. T72515

Encl: (1) USRD Charts 1 through 121 and Table 1  
(2) USRD Drawing 62785

1. Measurements on the subject transducers were made in the Anechoic Tank Facility during the period 4 through 11 April 1996 as arranged in reference (a). Mr. T. Howarth of the Naval Research Laboratory, Washington, DC was present to specify and assist with the measurements. Funds for this service were provided by reference (b).

2. Free-field voltage sensitivity (FFVS), transmitting voltage response (TVR), and directional response (DR) in the horizontal (XY) plane were measured in the frequency range 2.0 to 200 kHz, at the water temperatures 4 and 22°C, and at hydrostatic pressures to 6895 kPa (703.1 m). Conditions and results of the measurements are presented in enclosure (1).

3. Piezocomposite transducers serials 4-44, 4-67, 4-70, and 4K-1 were observed to perform intermittently under the conditions shown below.

	4°C		22°C	
	3448 kPa	6895 kPa	3448 kPa	6895 kPa
4-44		*		*
4-67	*	*	*	*
4-70	*	*	*	*
4K-1				*

\* Intermittent Performance

Further dissemination only as directed by  
Commanding Officer, Naval Undersea Warfare  
Center (29 APR 1996) or higher DoD  
authority.

3965  
Ser X72500-0779  
29 APR 1996

USRD CALIBRATION MEMORANDUM NO. 0779

4. Orientation was as described for a piston in enclosure (2). An arrow on the face of the transducer was in the direction of the +Z axis and the cable exited in the -X direction except where otherwise noted.



A. R. GARCEAU  
Project Leader



R. M. DRAKE  
Head, Acoustic Measurements T&E Branch

Copy to:  
NRL (Code 7135, T. Howarth) (4)  
NUWC-USRD (Code 251, R. Ting)  
(Code 2572, K. Benjamin)  
(Code 2582)



TABLE 1  
DATA DIRECTORY  
Piezocomposite Transducers

	CHART
Serial 4-44	
4°C	
FFVS .....	1
TVR .....	2
DR .....	3-15
22°C	
FFVS .....	16
TVR .....	17
DR .....	18-29
Serial 4-67	
4°C	
FFVS .....	30
TVR .....	31
DR .....	32-43
22°C	
FFVS .....	44
TVR .....	45
DR .....	46-57
Serial 4-70	
4°C	
FFVS .....	58
TVR .....	59
DR .....	60-71
22°C	
FFVS .....	72
TVR .....	73
DR .....	74-85

TABLE 1  
Piezocomposite Transducers

		CHART
Serial 4K-1		
4°C		
FFVS .....		86
TVR .....		87
DR .....		88-103
22°C		
FFVS .....		104
TVR .....		105
DR .....		106-121

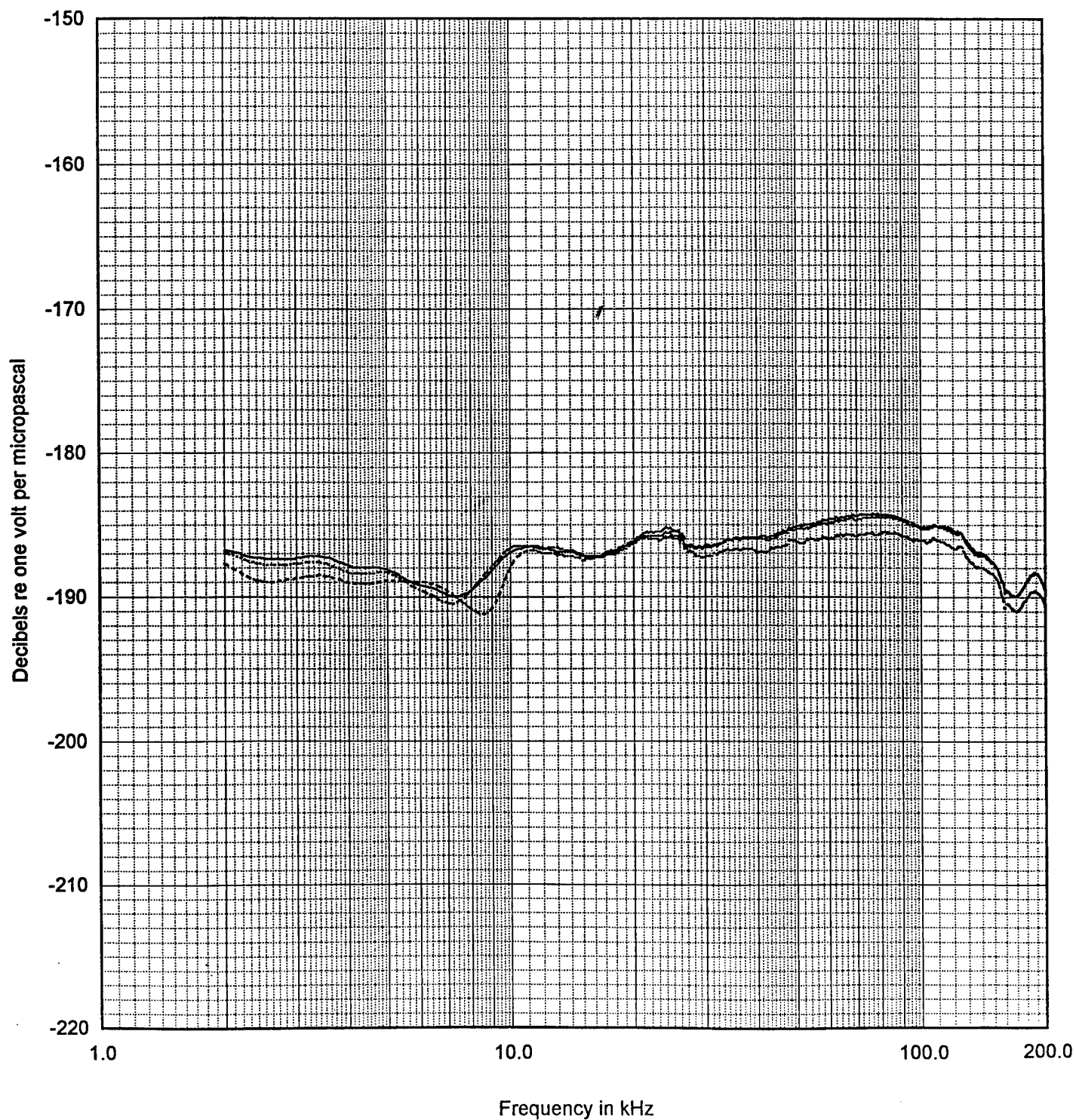
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-44

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 4° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
..... 16 kPa ( 1.6 m) After Pressure



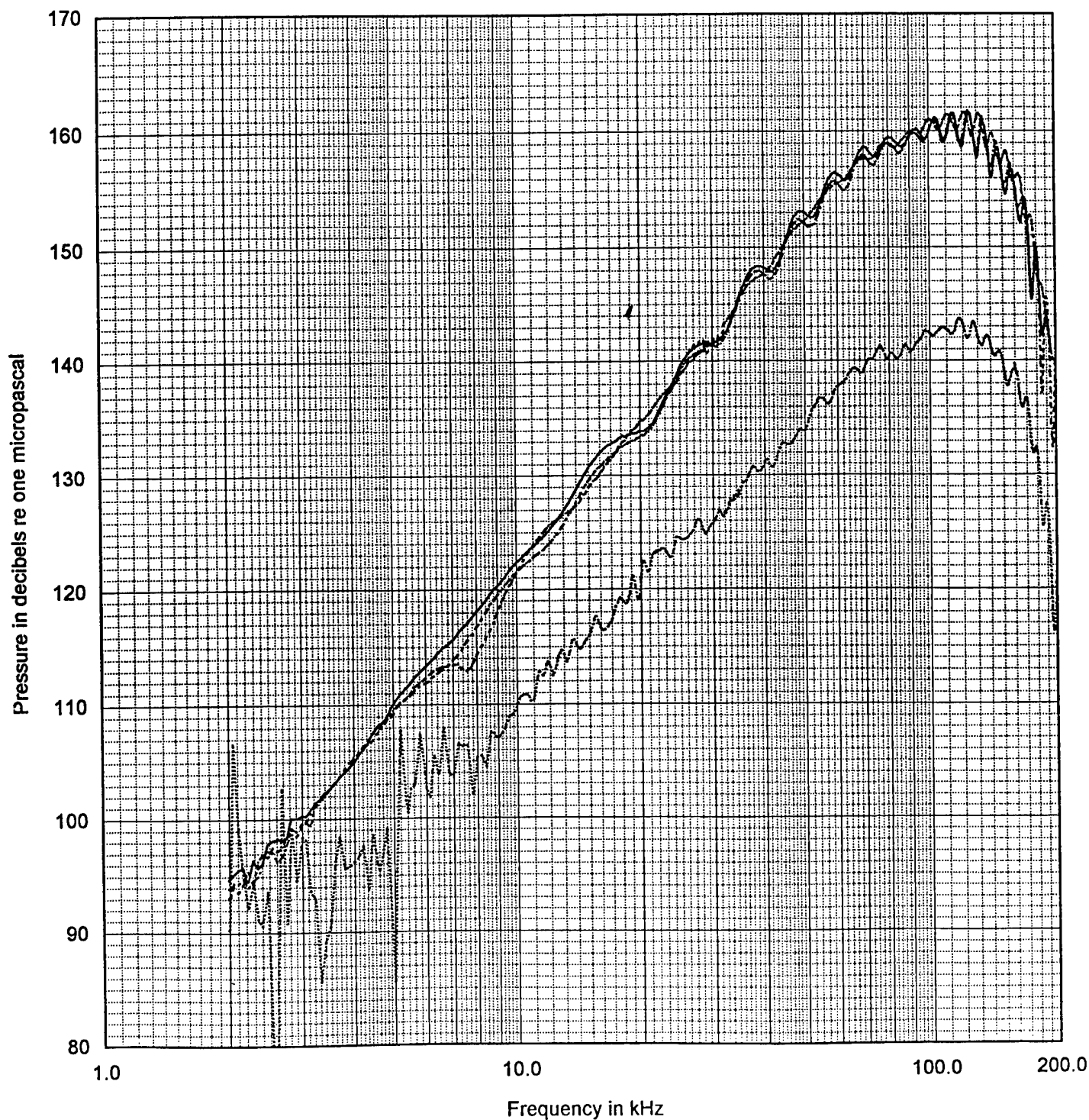
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-44

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
----- 6895 kPa ( 703.1 m)  
----- 16 kPa ( 1.6 m) After Pressure



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USRD NO. 0779-3  
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APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m )

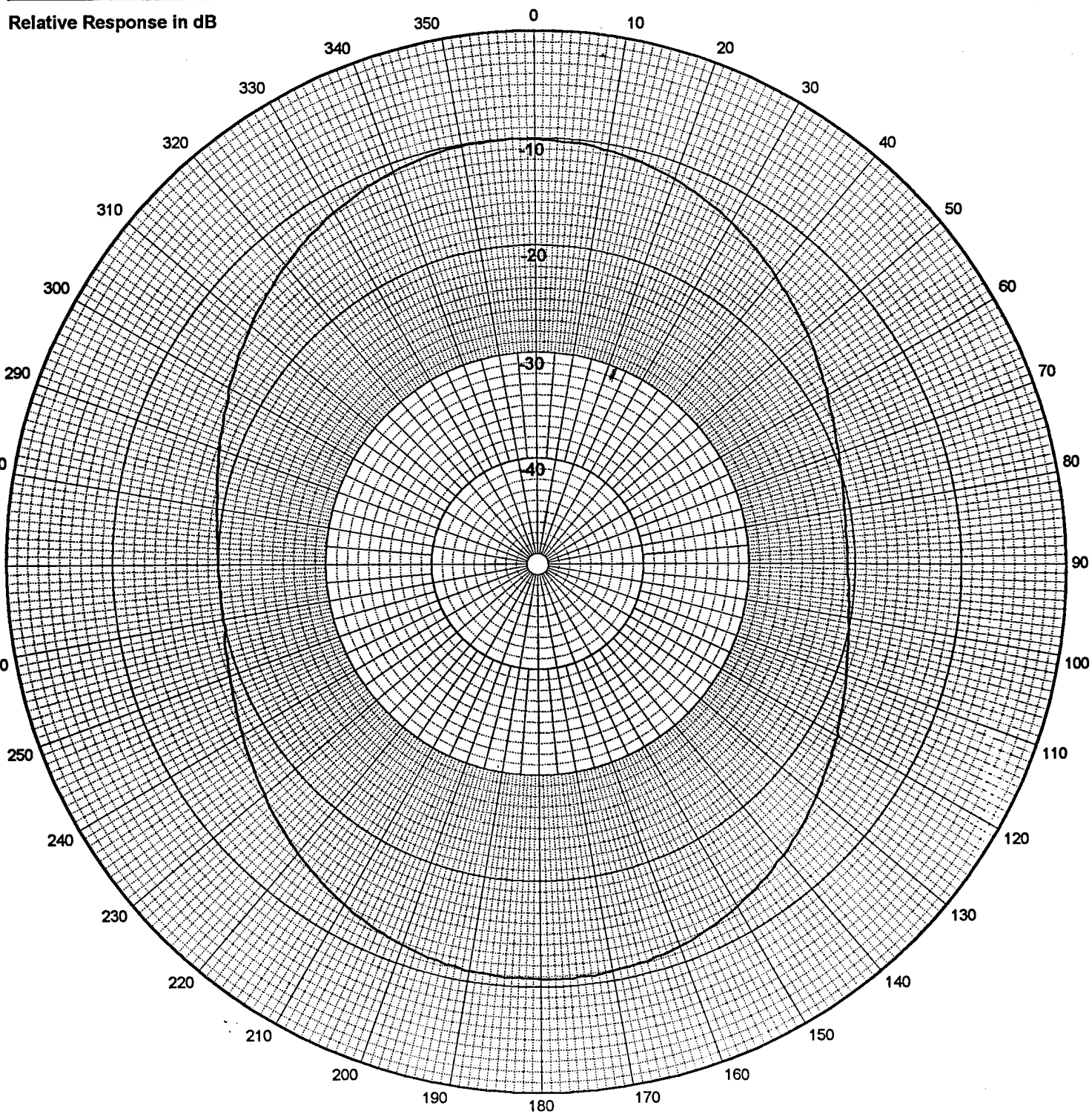
Water Temperature: 4° C

Transmit

XY Plane

10 kHz

Relative Response in dB



Degrees



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m )

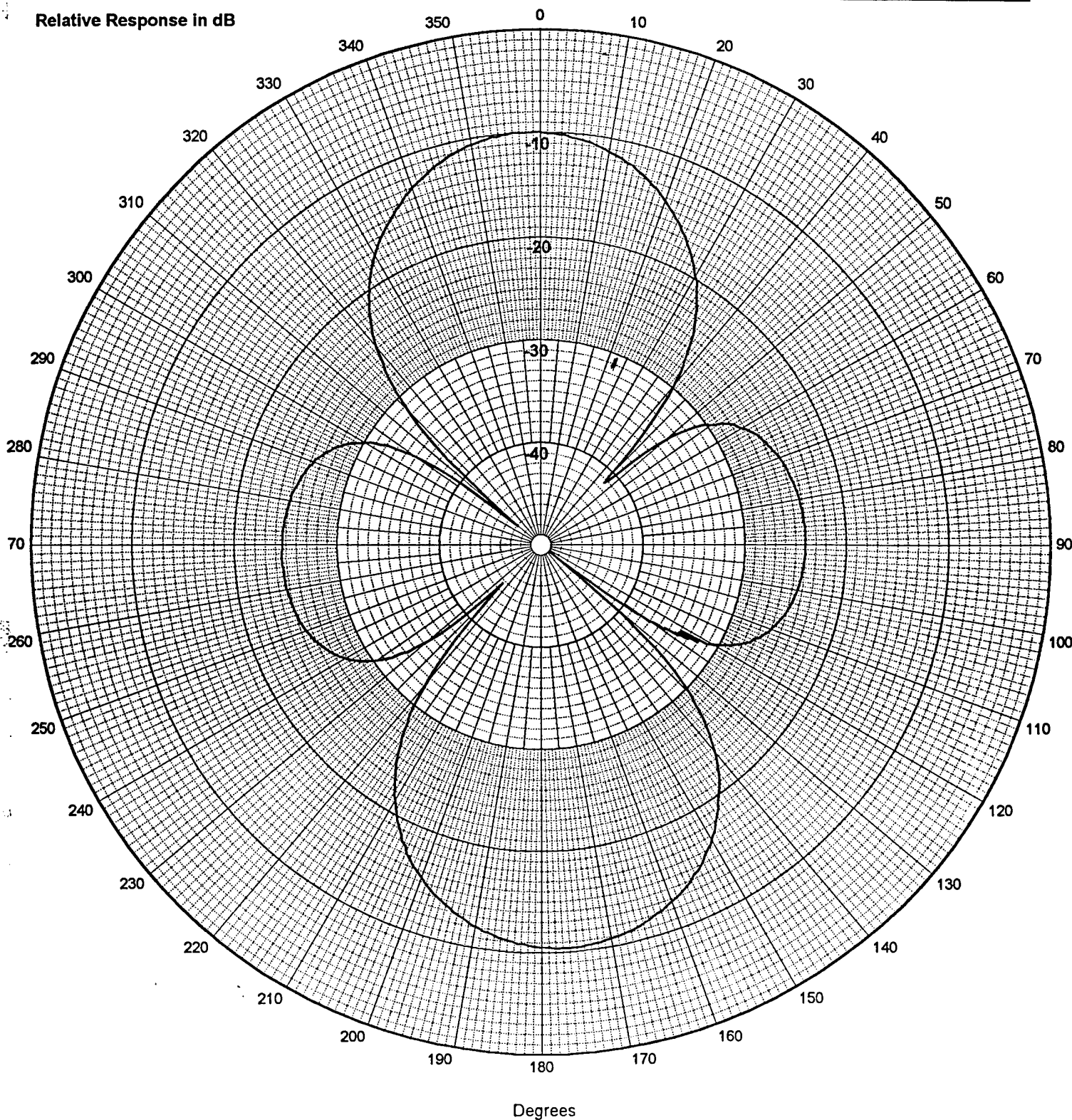
Water Temperature: 4° C

Transmit

XY Plane

20 kHz

Relative Response in dB



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USRD NO. 0779-5  
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APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m )

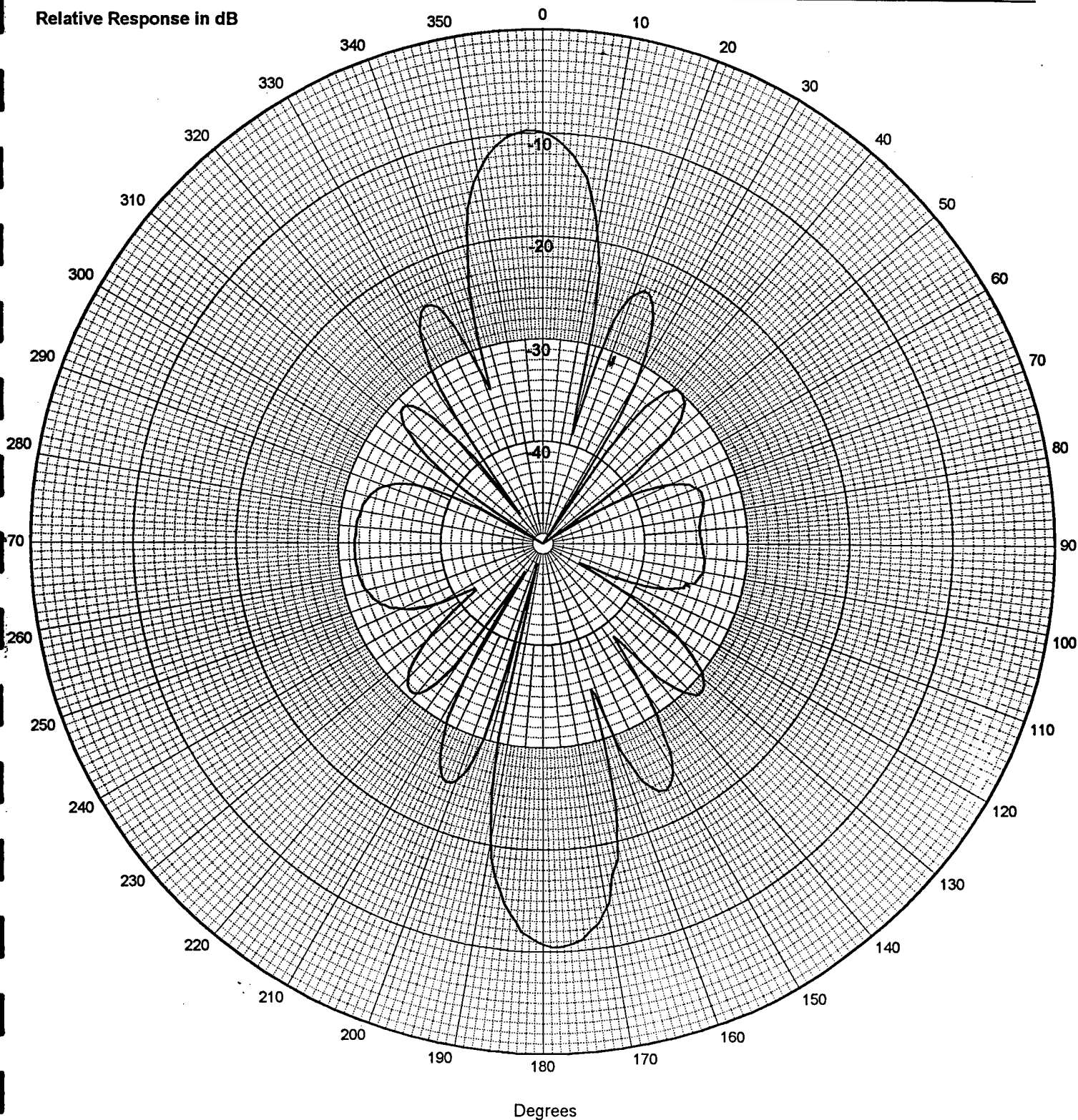
Water Temperature: 4° C

Transmit

XY Plane

50 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

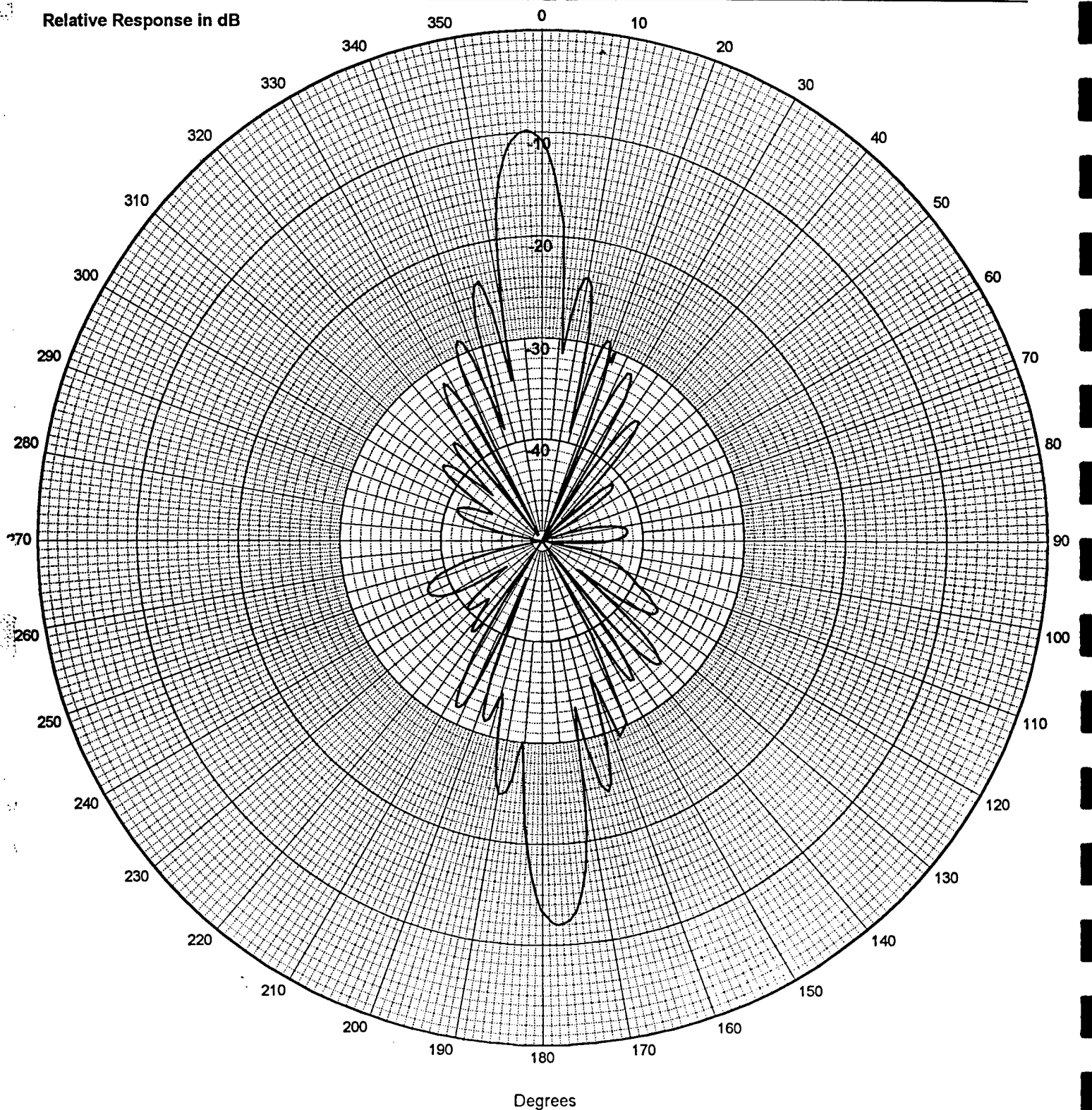
Hydrostatic Pressure: 16 kPa ( 1.6 m )

Water Temperature: 4° C

Transmit

XY Plane

100 kHz



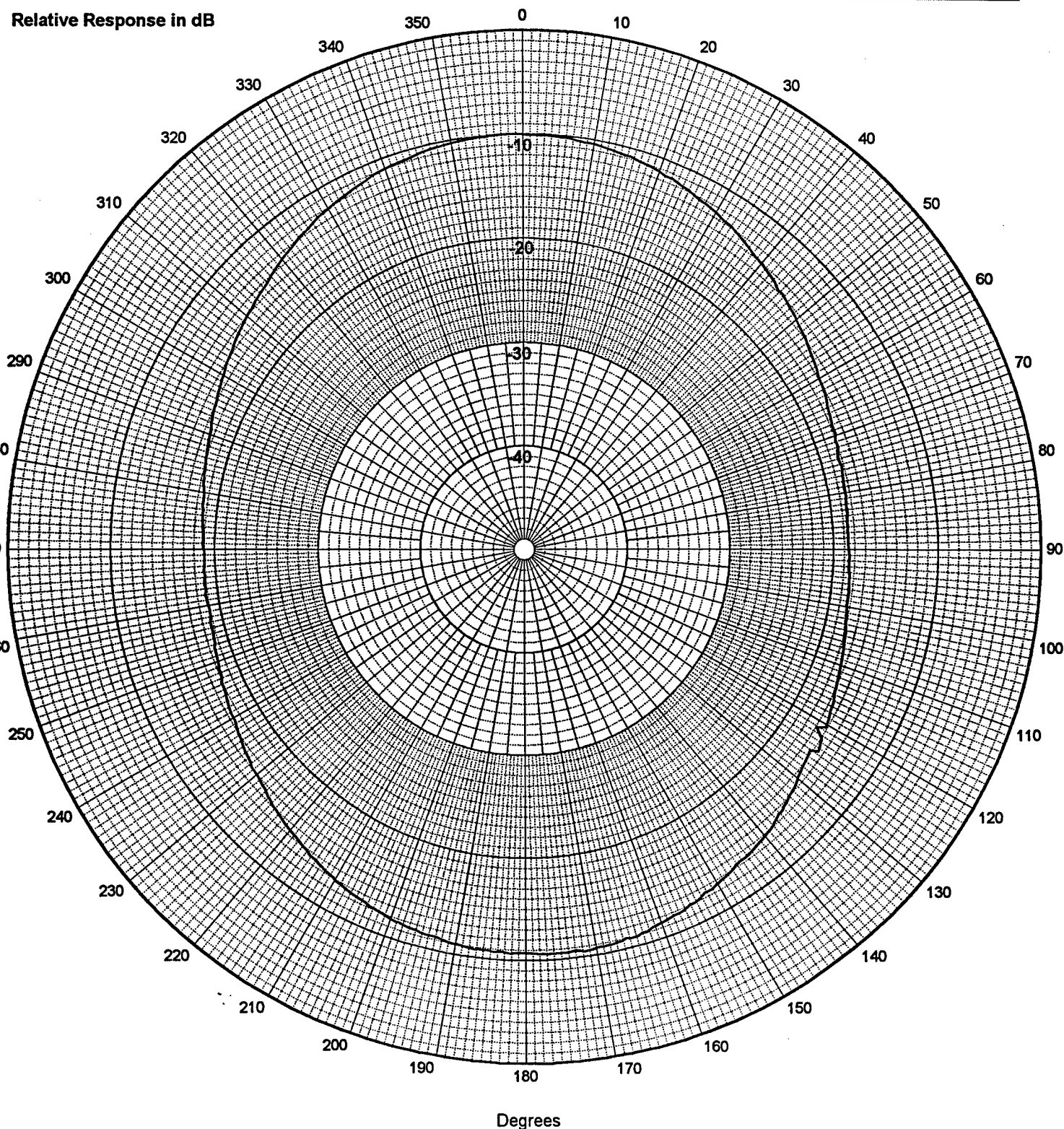
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UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0779-7  
ANECHOIC TANK FACILITY  
APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB

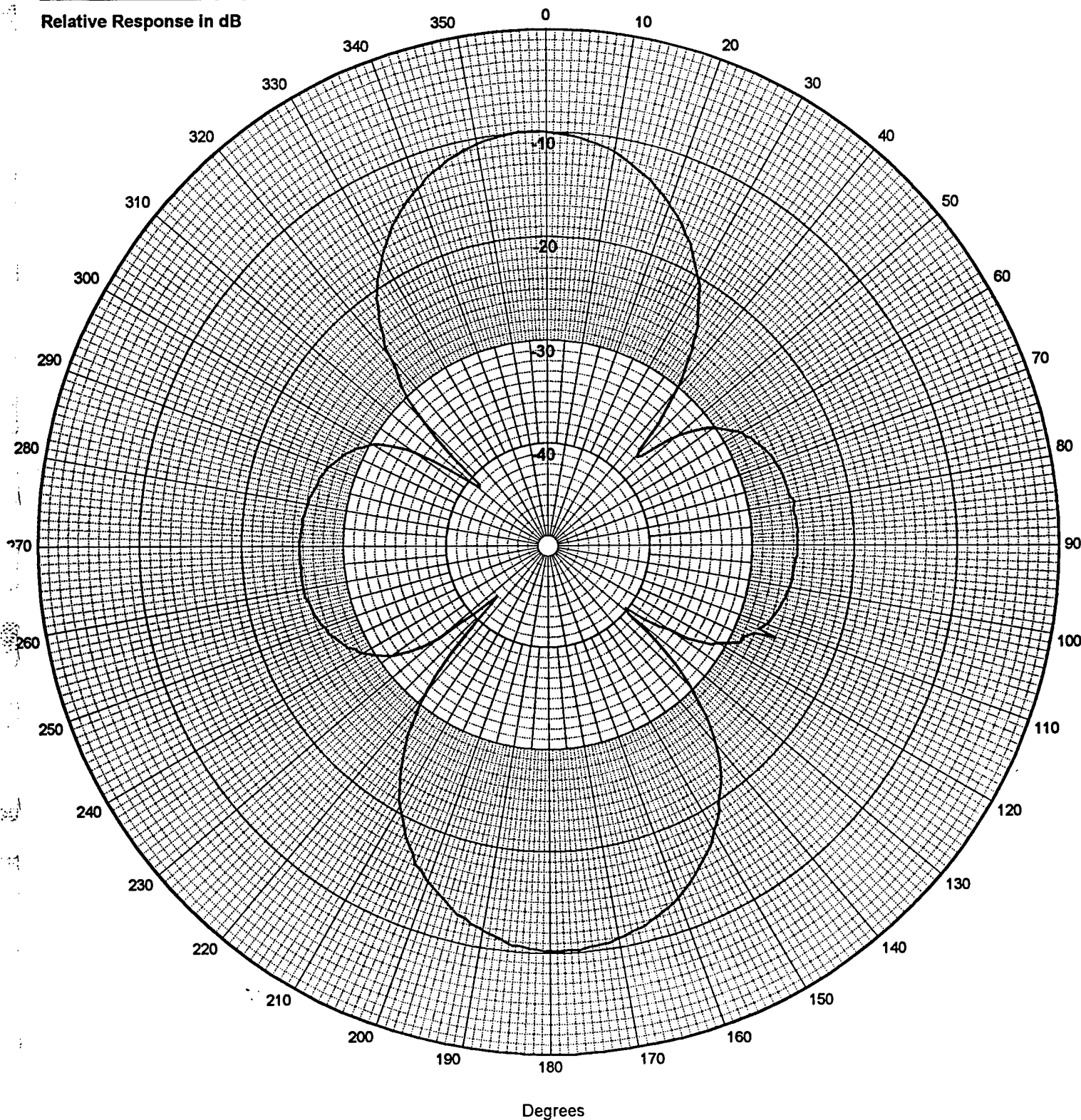




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB





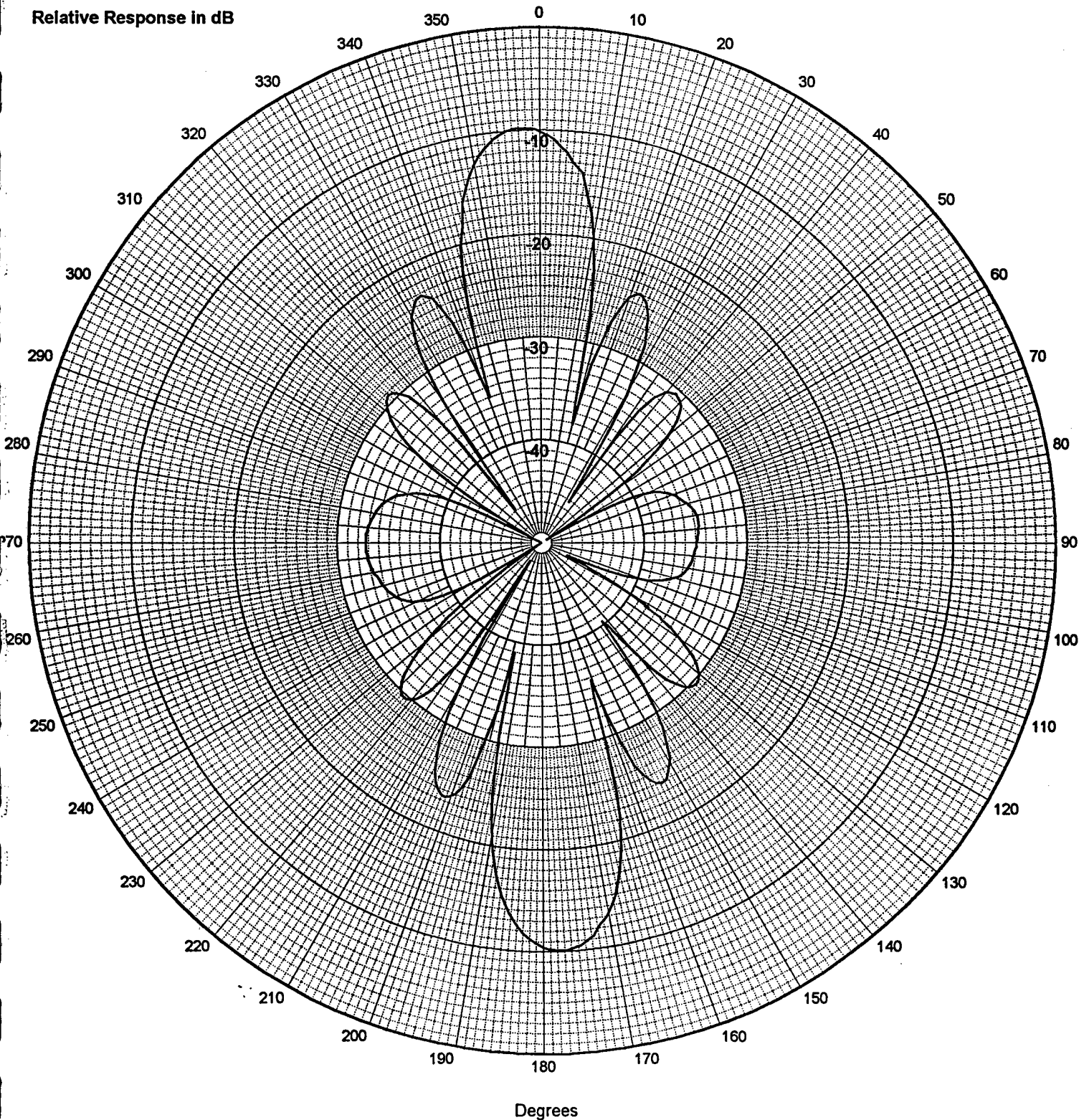
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0779-9  
ANECHOIC TANK FACILITY  
APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
50 kHz

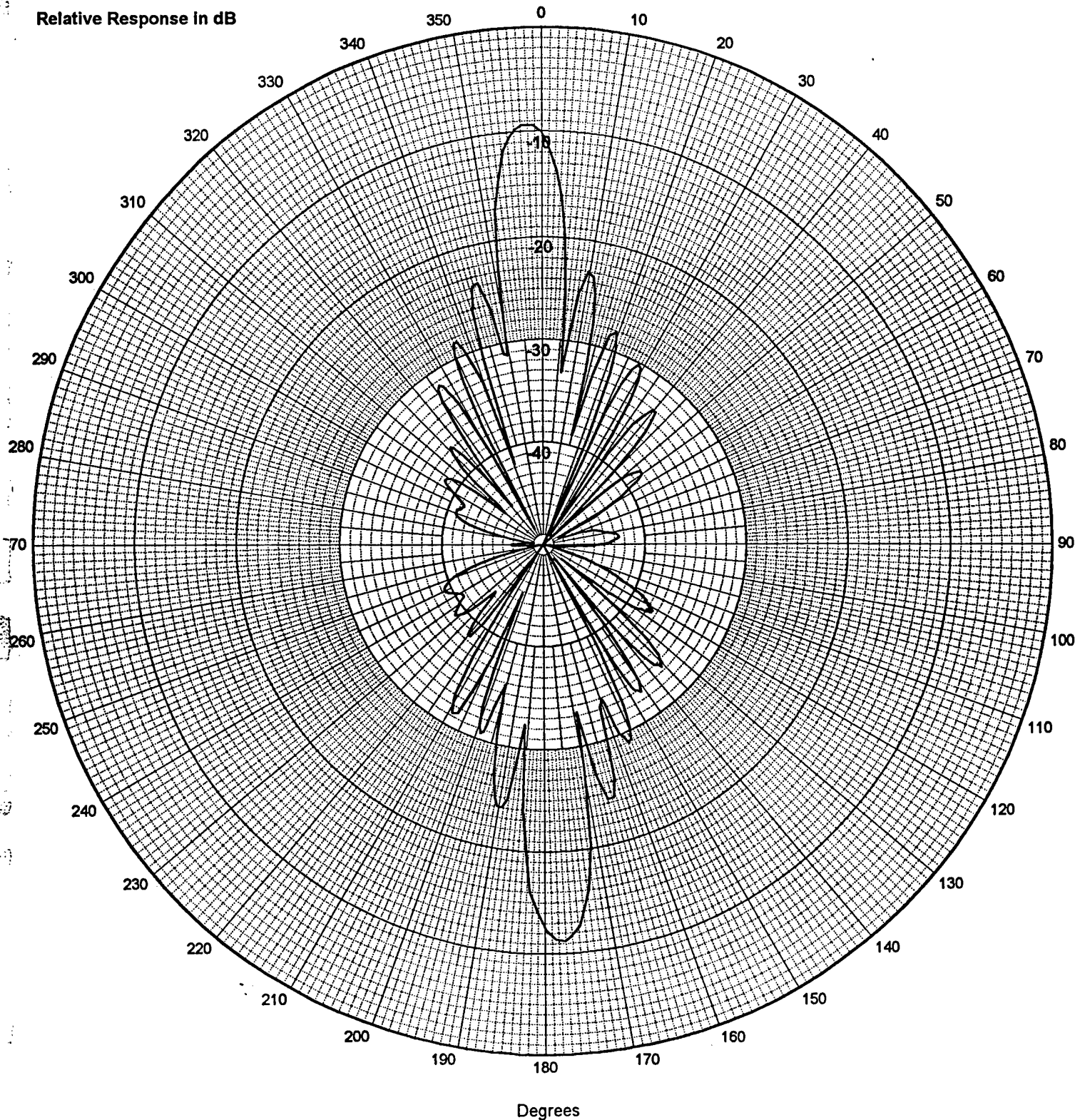
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



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USRD NO. 0779-11  
ANECHOIC TANK FACILITY  
APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 6895 kPa ( 703.1 m )

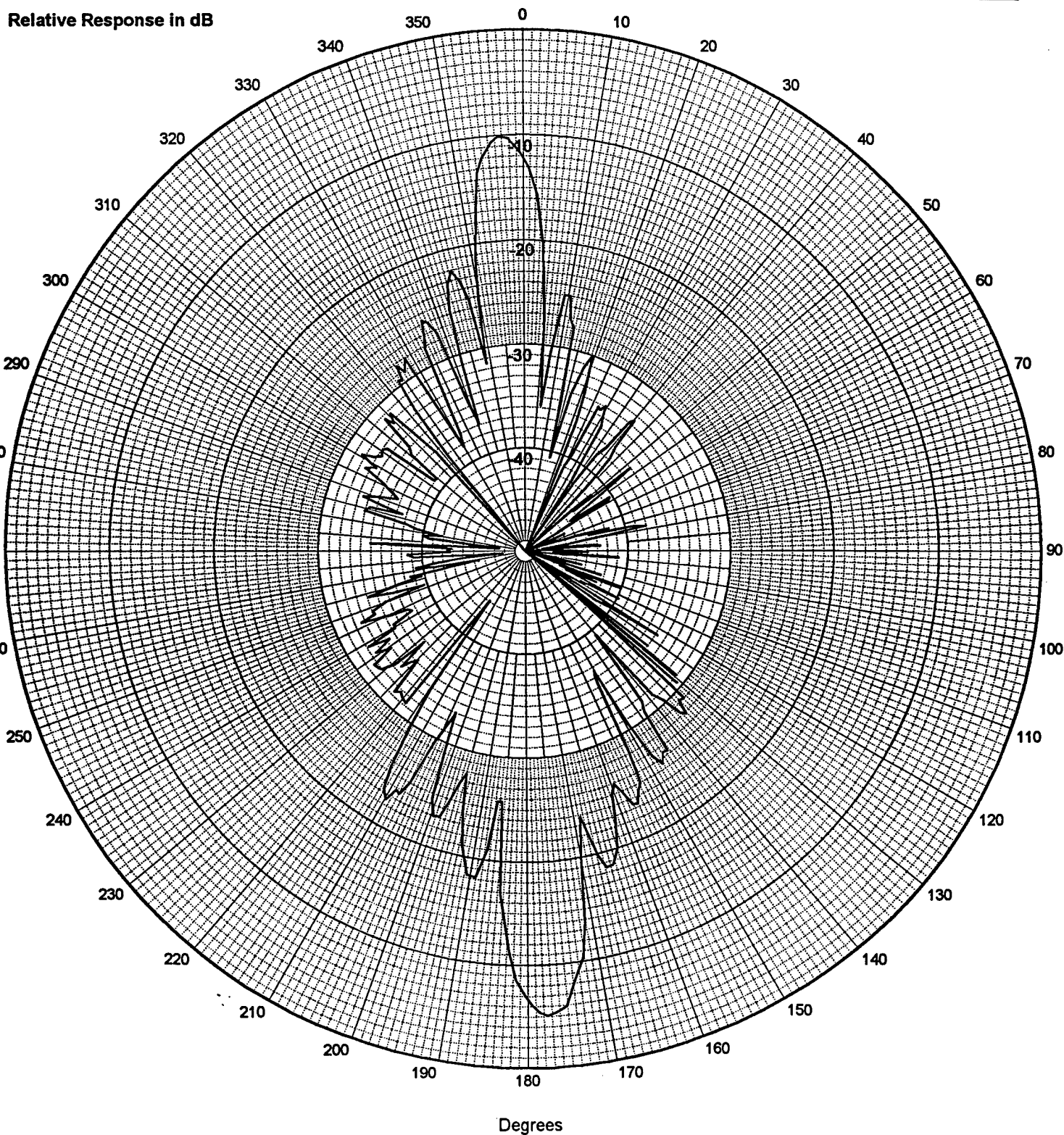
Water Temperature: 4° C

Transmit

XY Plane

100 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

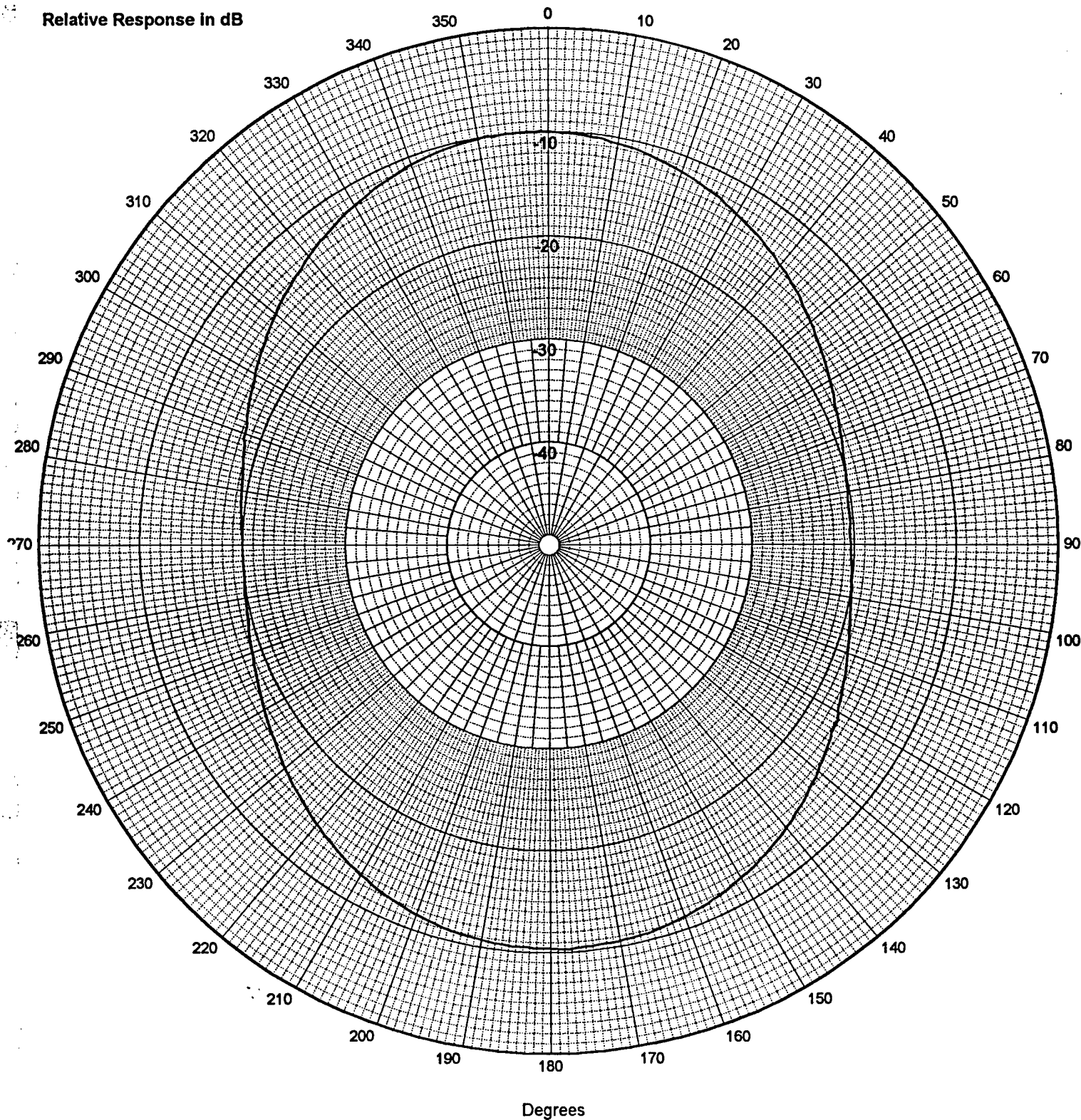
Water Temperature: 4° C

Transmit

XY Plane

10 kHz

Relative Response in dB





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UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0779-13  
ANECHOIC TANK FACILITY  
APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

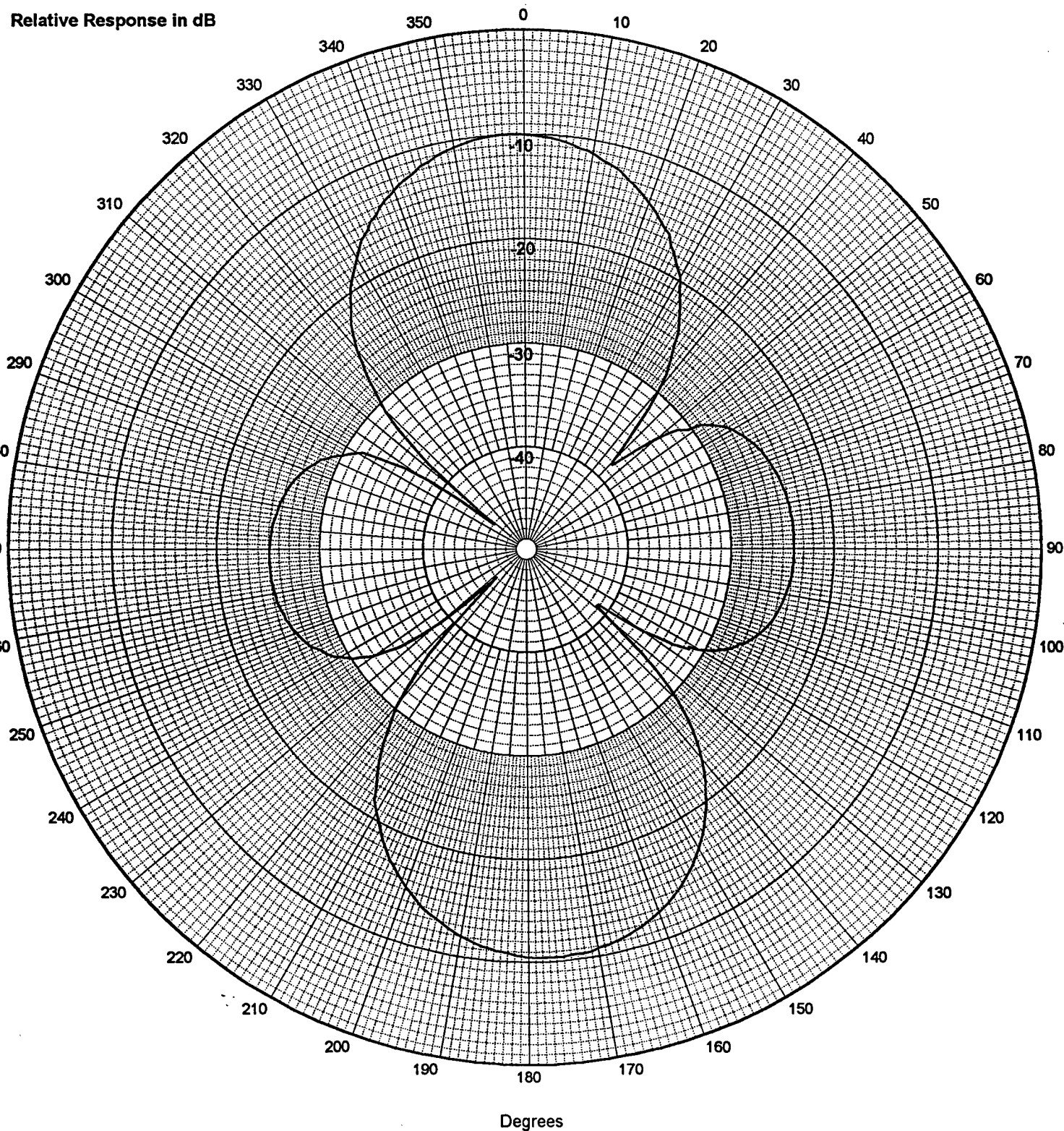
Water Temperature: 4° C

Transmit

XY Plane

20 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

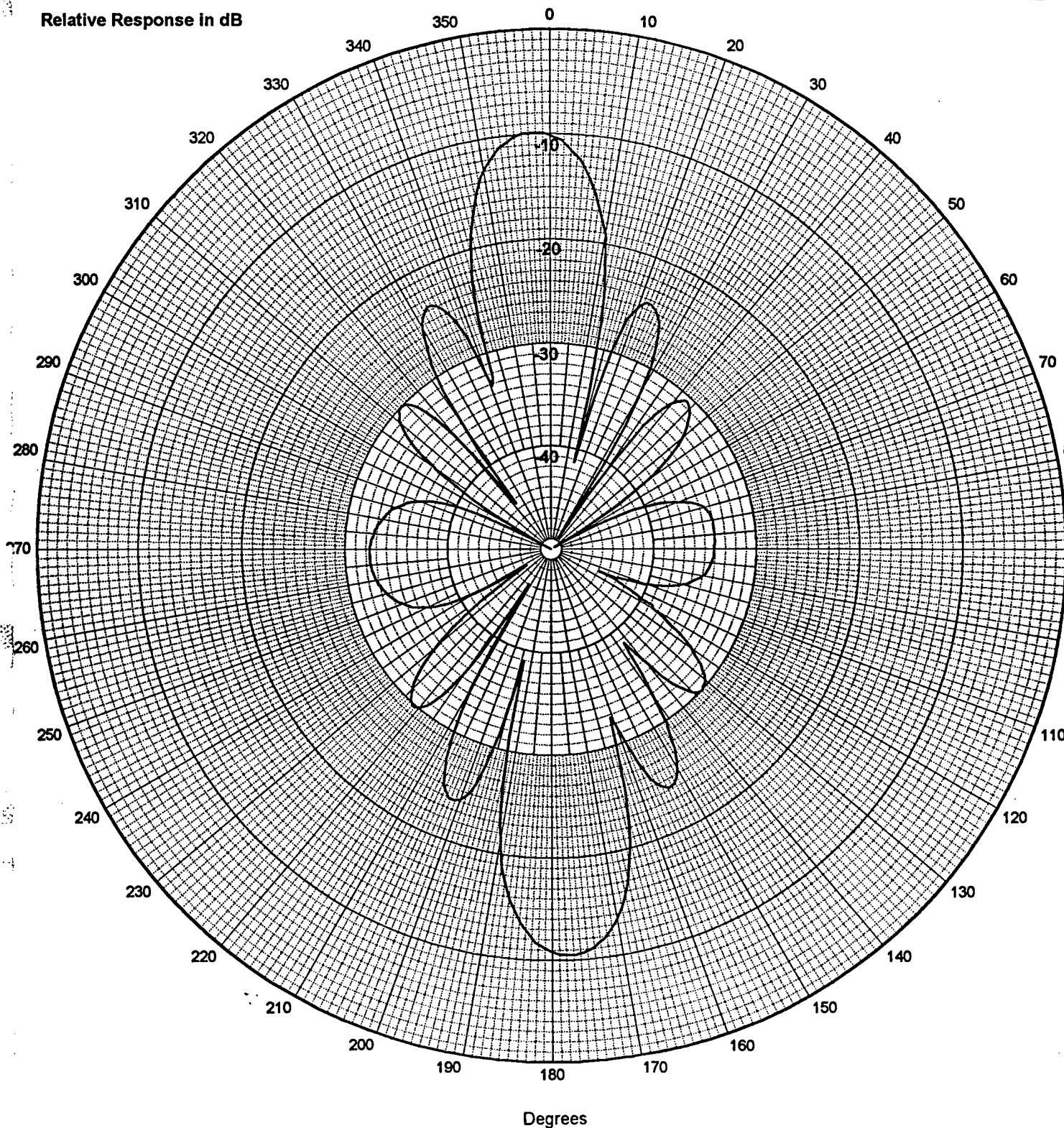
Water Temperature: 4° C

Transmit

XY Plane

50 kHz

Relative Response in dB



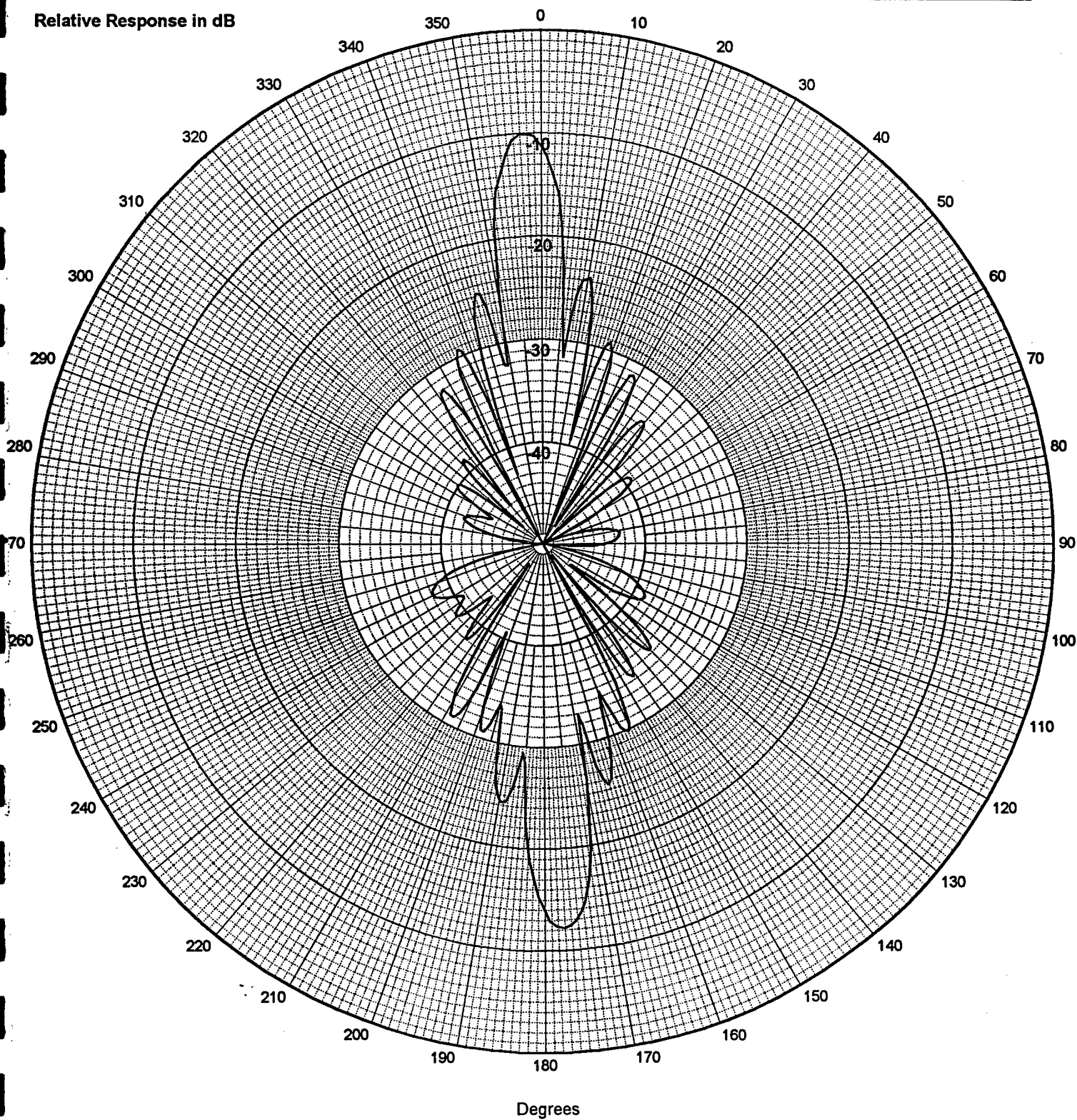
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USRD NO. 0779-15  
ANECHOIC TANK FACILITY  
APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



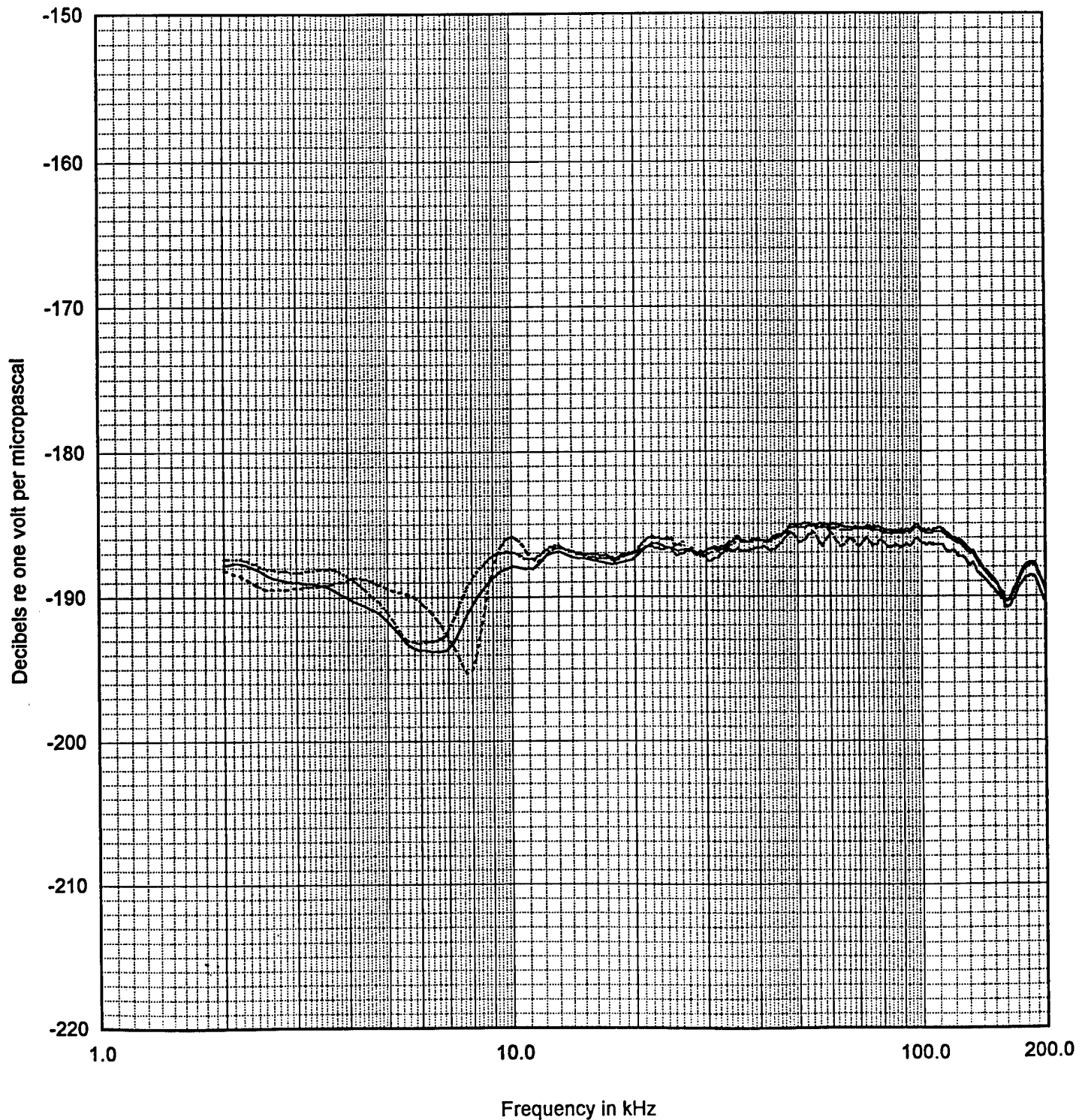
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-44

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 22° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
- · - · - 16 kPa ( 1.6 m) After Pressure



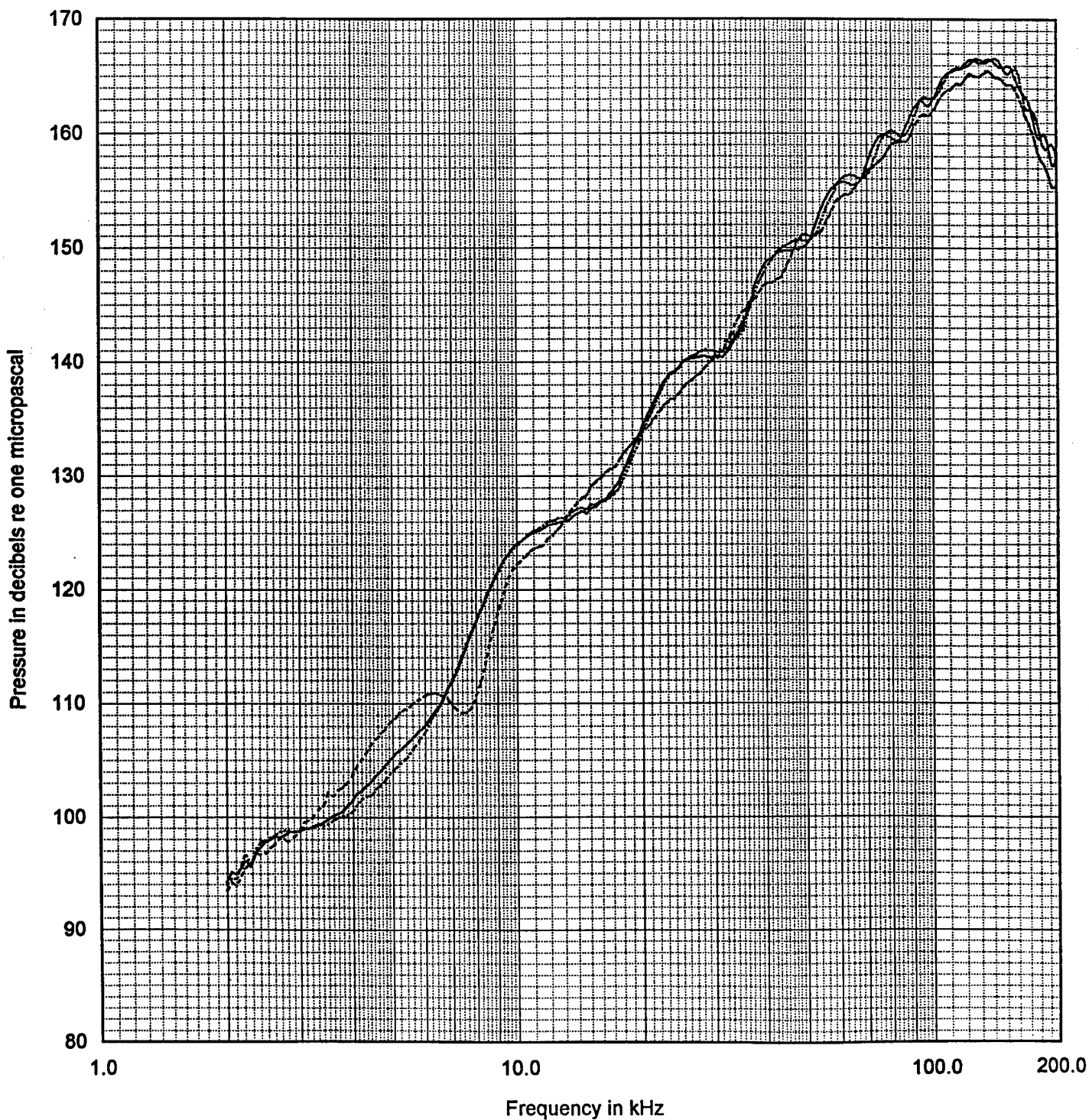
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-44

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

————— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 16 kPa ( 1.6 m) After Pressure





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m )

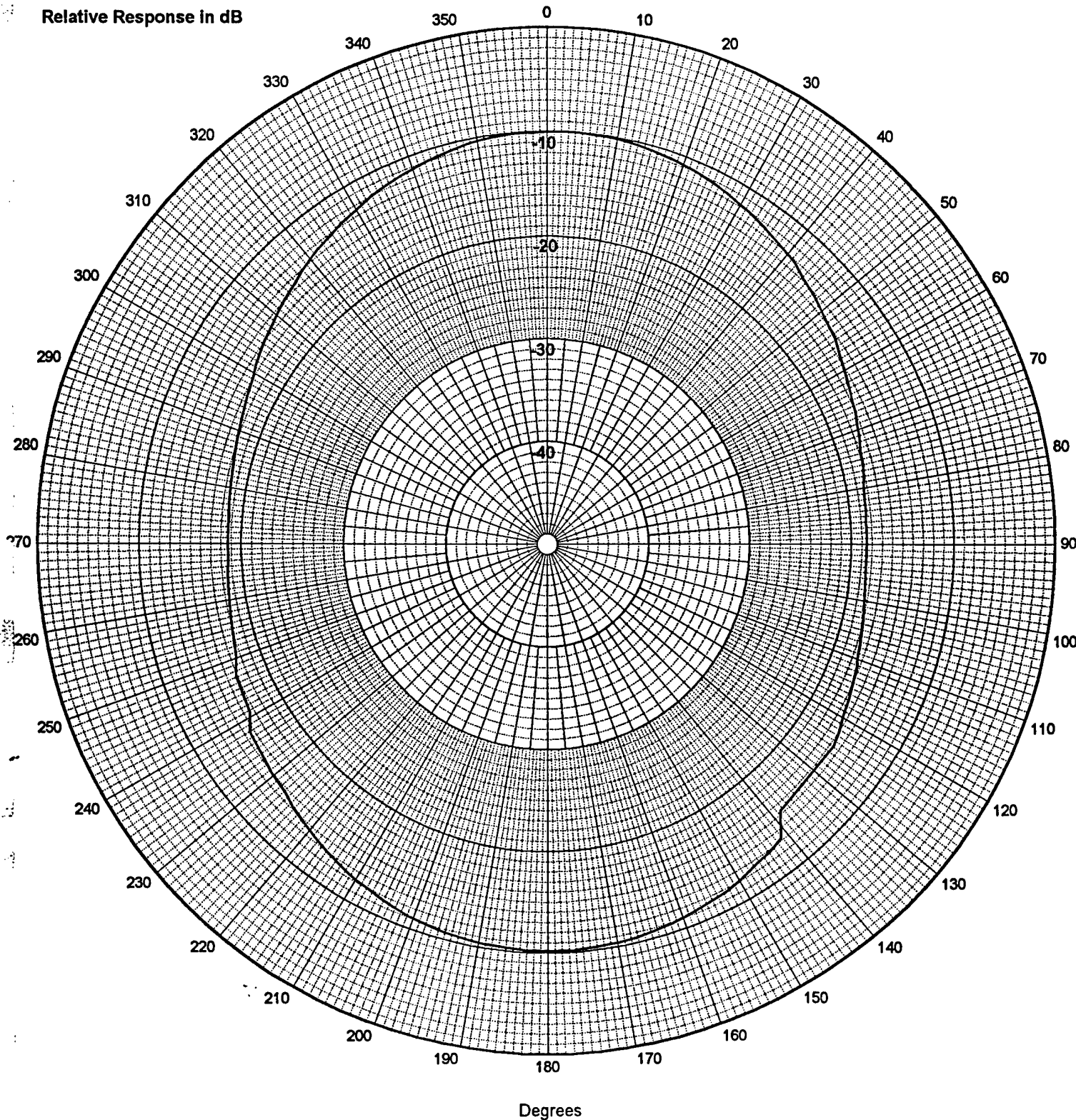
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB





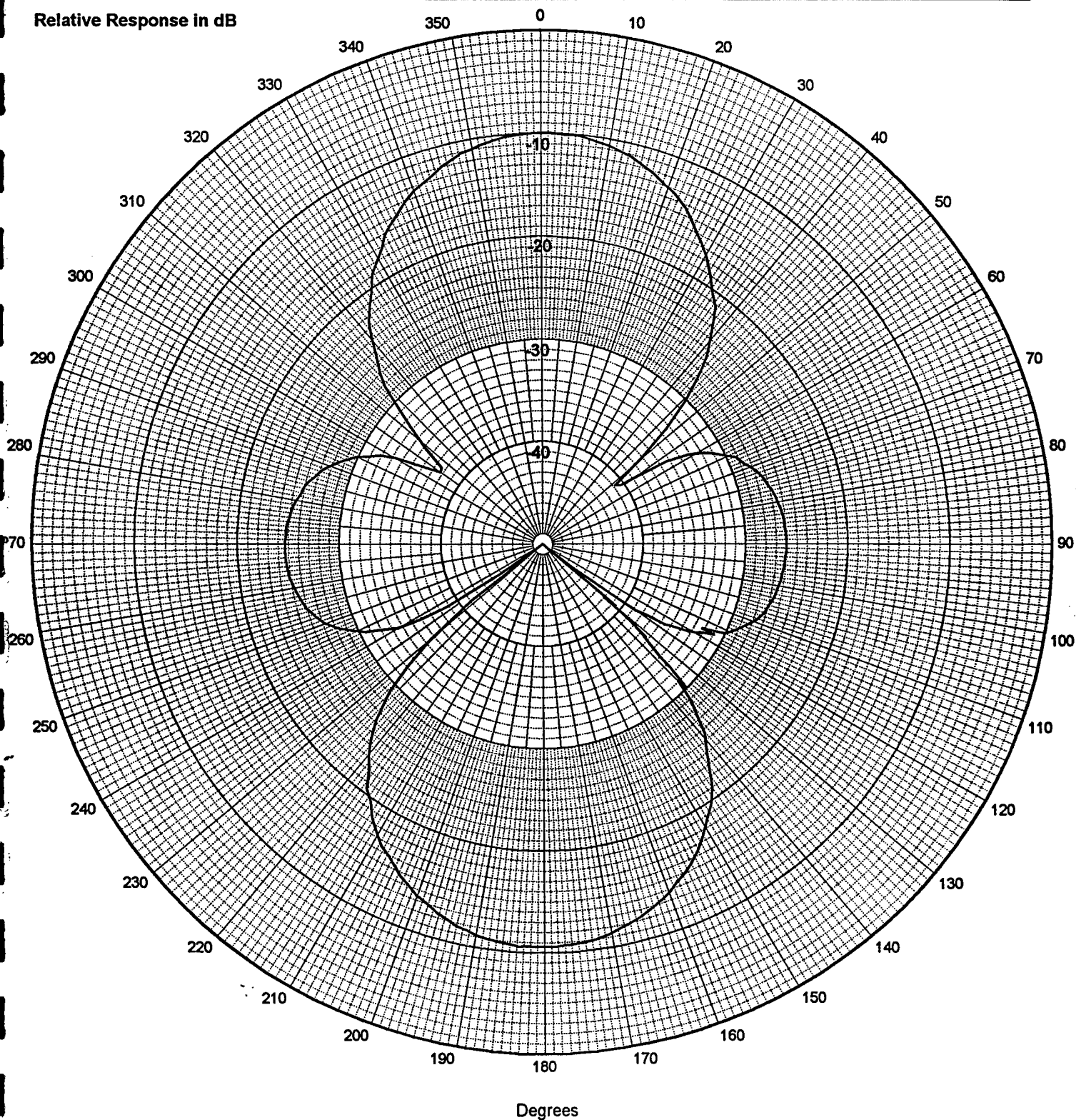
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UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0779-19  
ANECHOIC TANK FACILITY  
APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 16 kPa ( 1.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

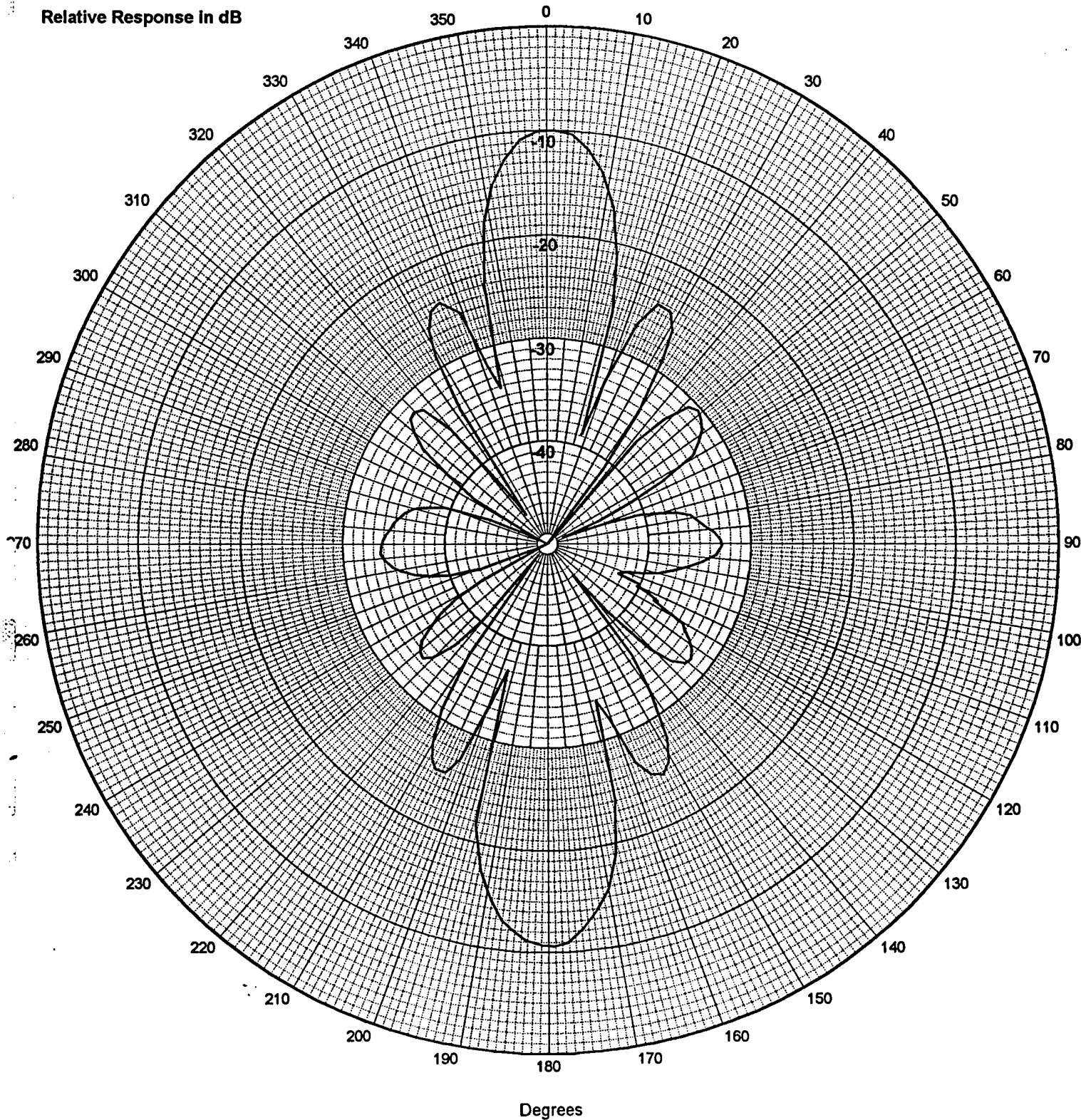
Hydrostatic Pressure: 16 kPa ( 1.6 m )

Water Temperature: 22° C

Transmit

XY Plane

50 kHz



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APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

Hydrostatic Pressure: 16 kPa ( 1.6 m )

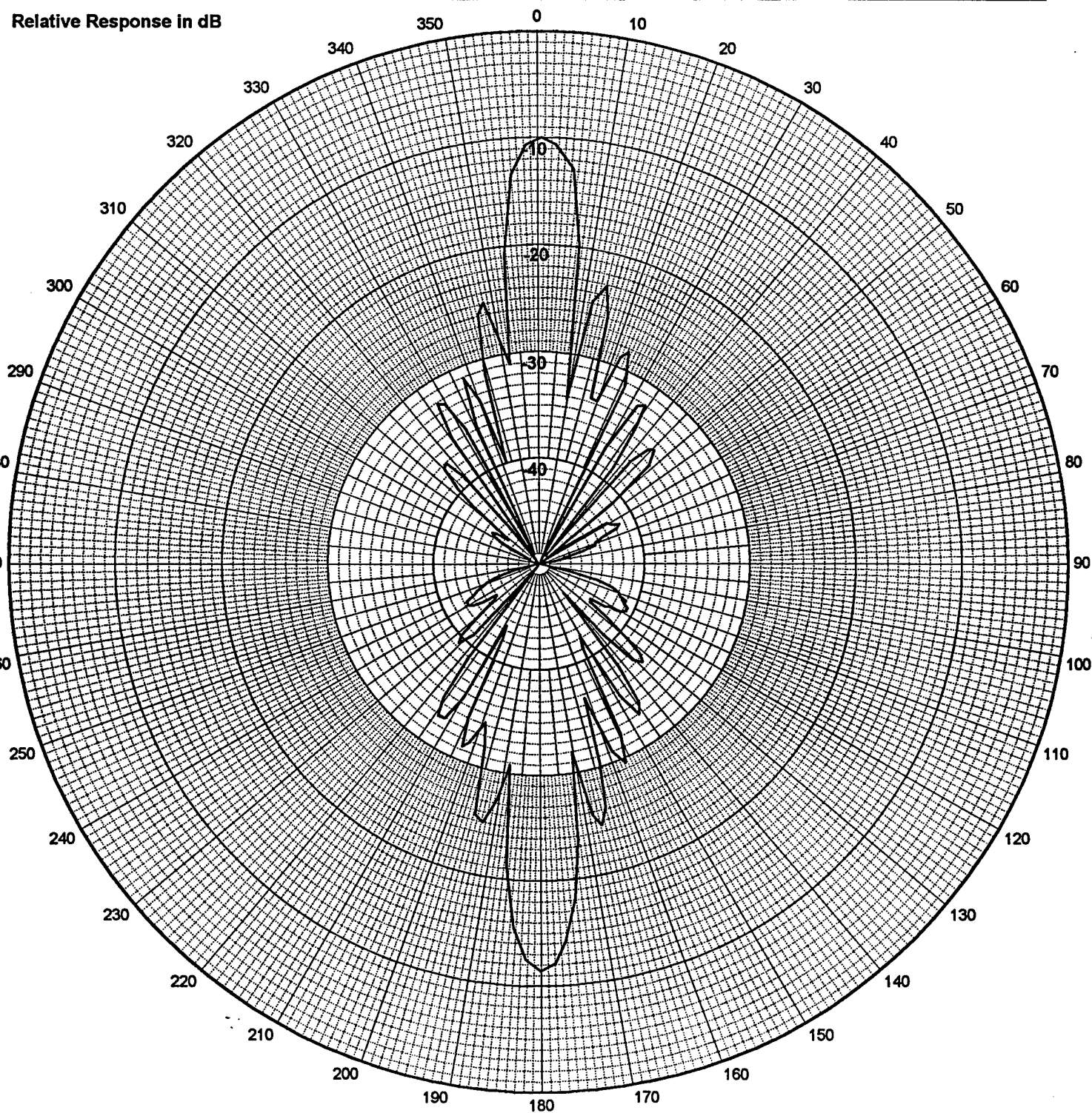
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB

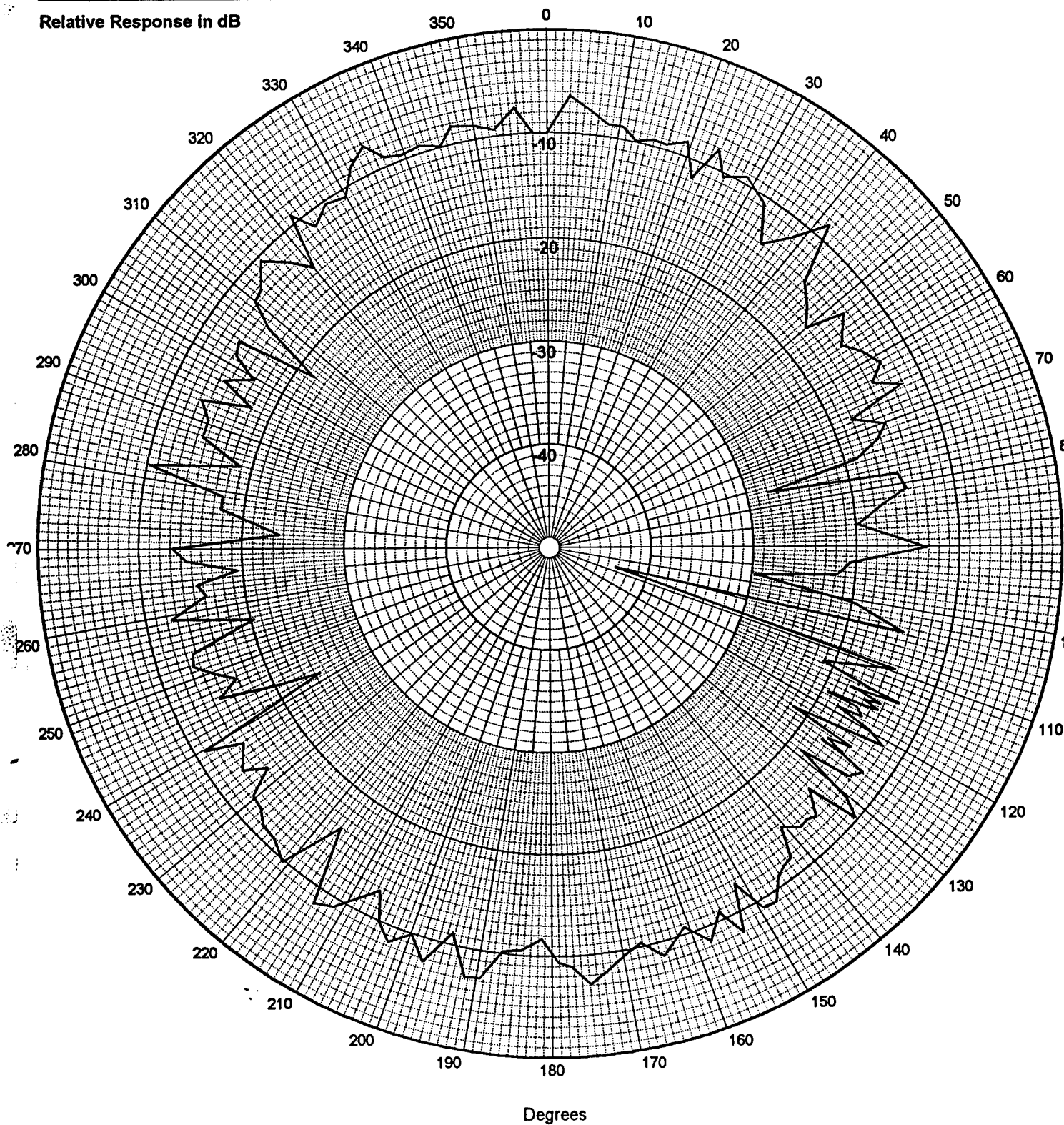


Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB





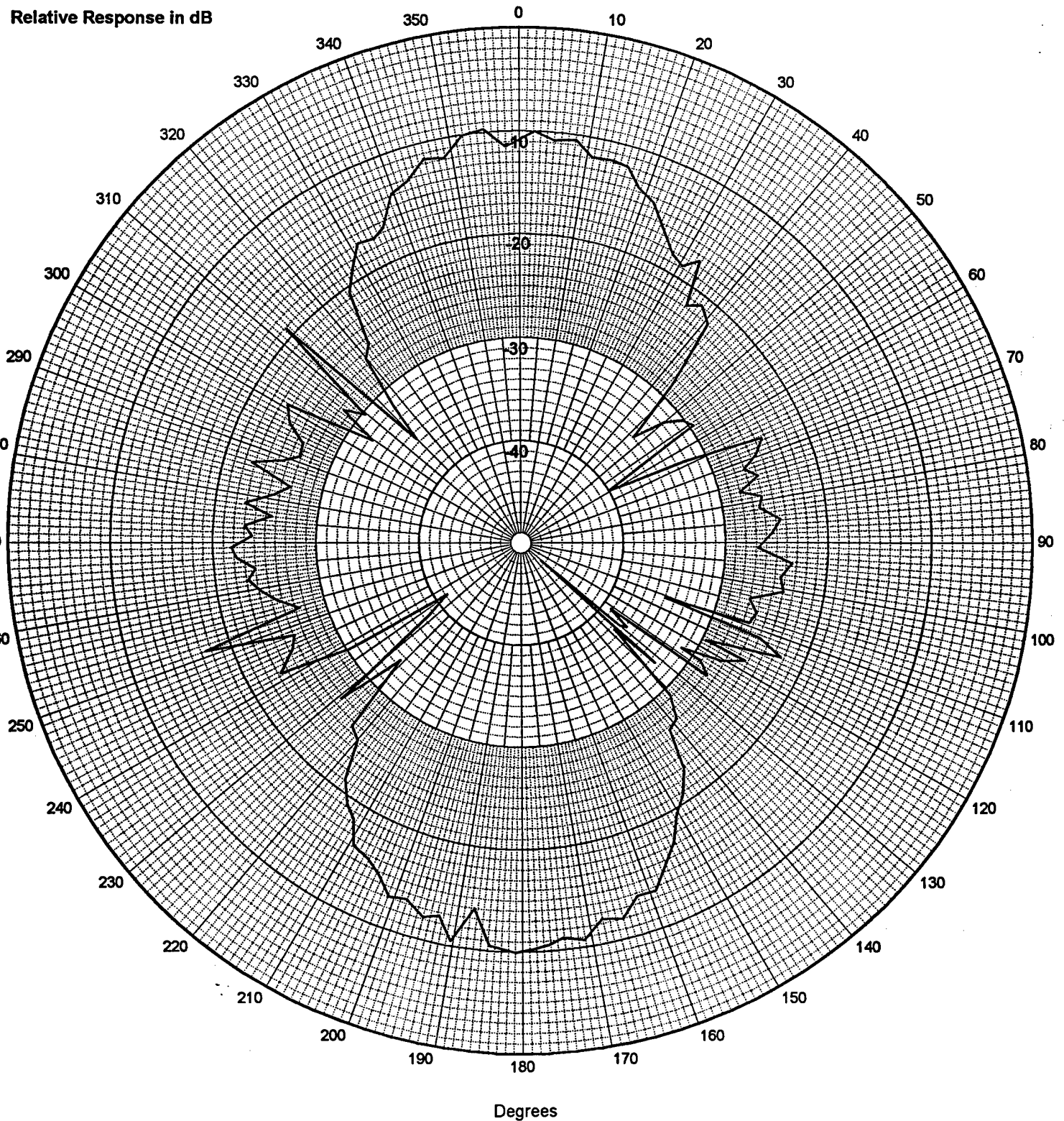
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB

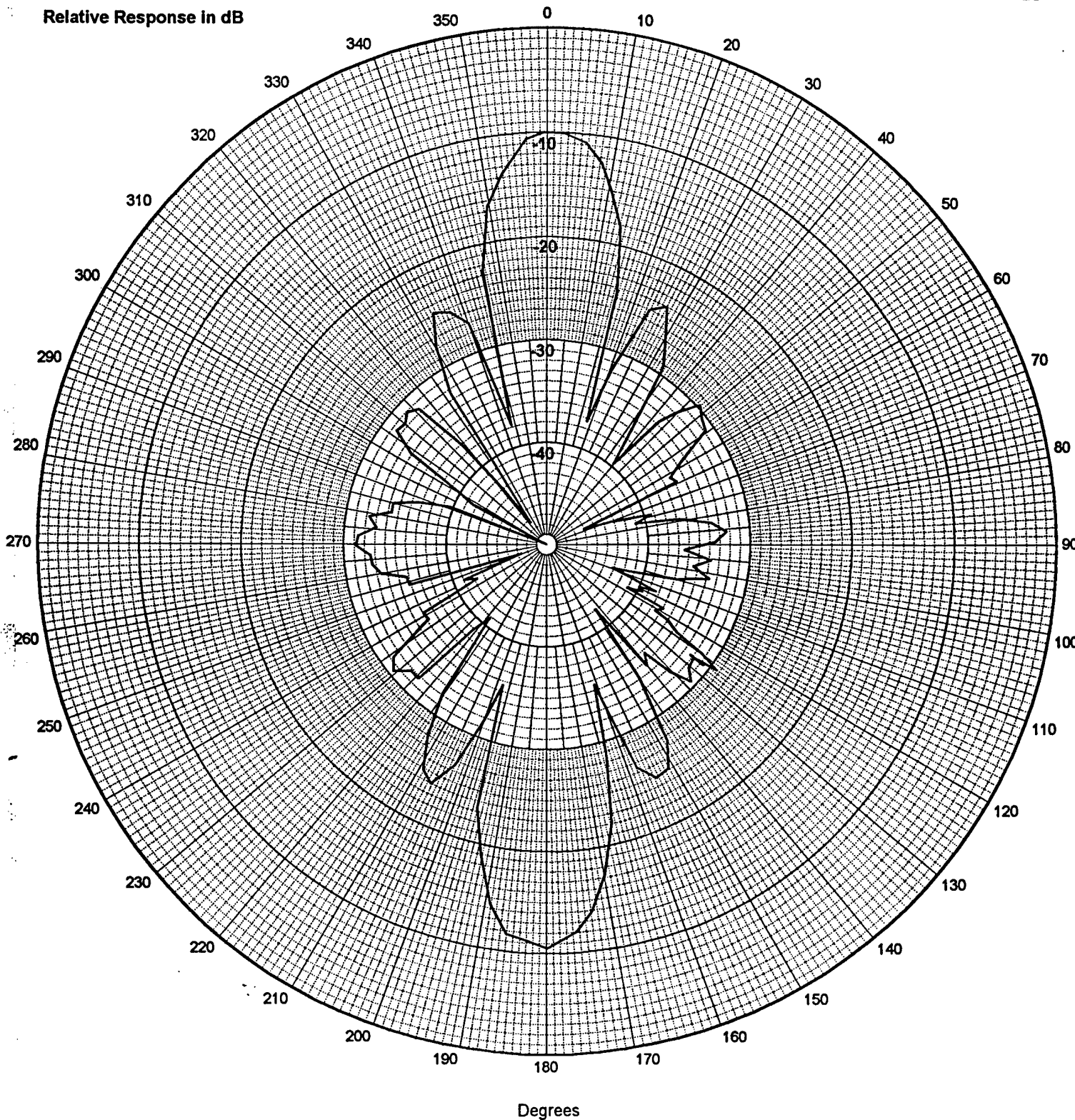




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



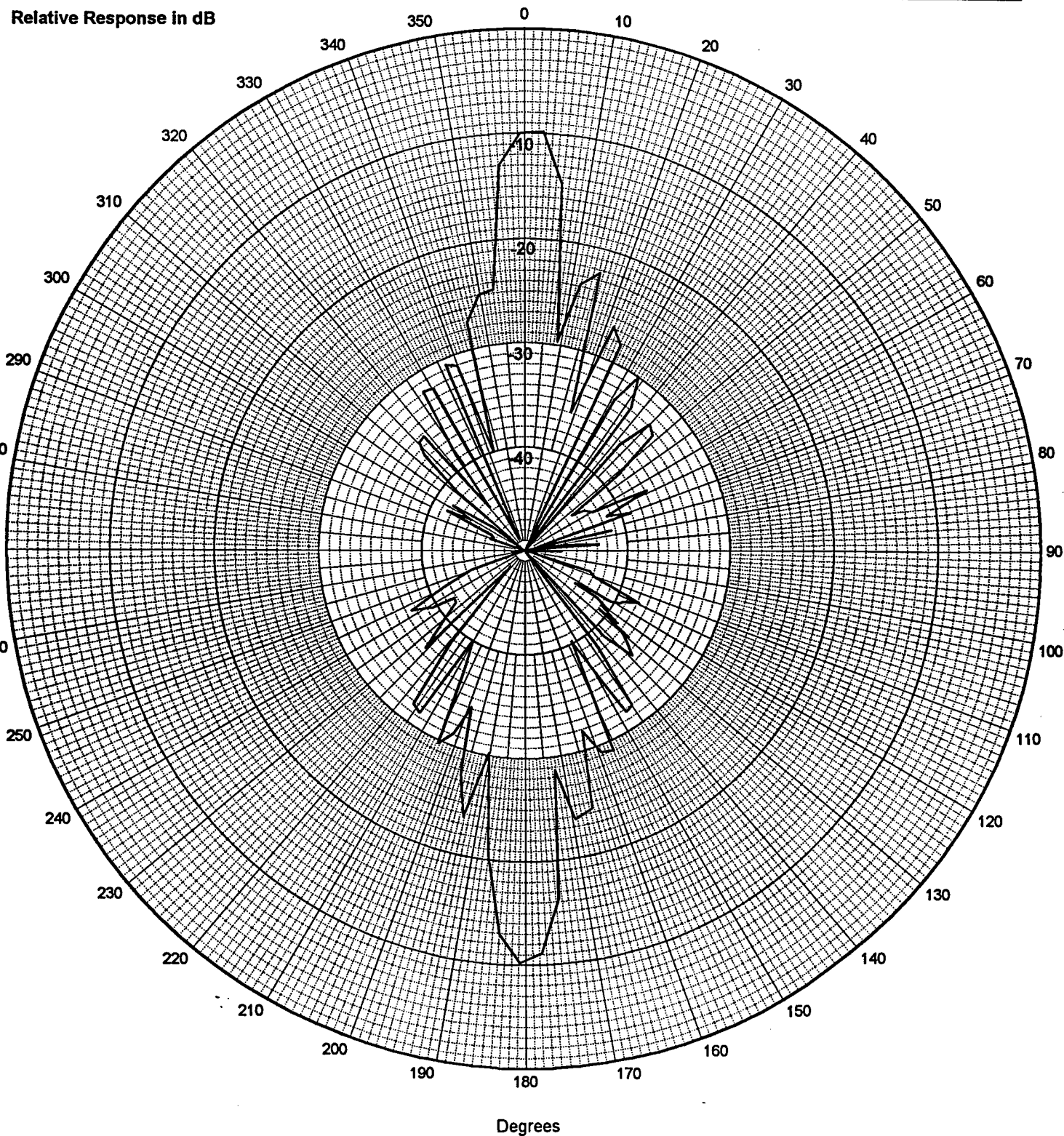
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44

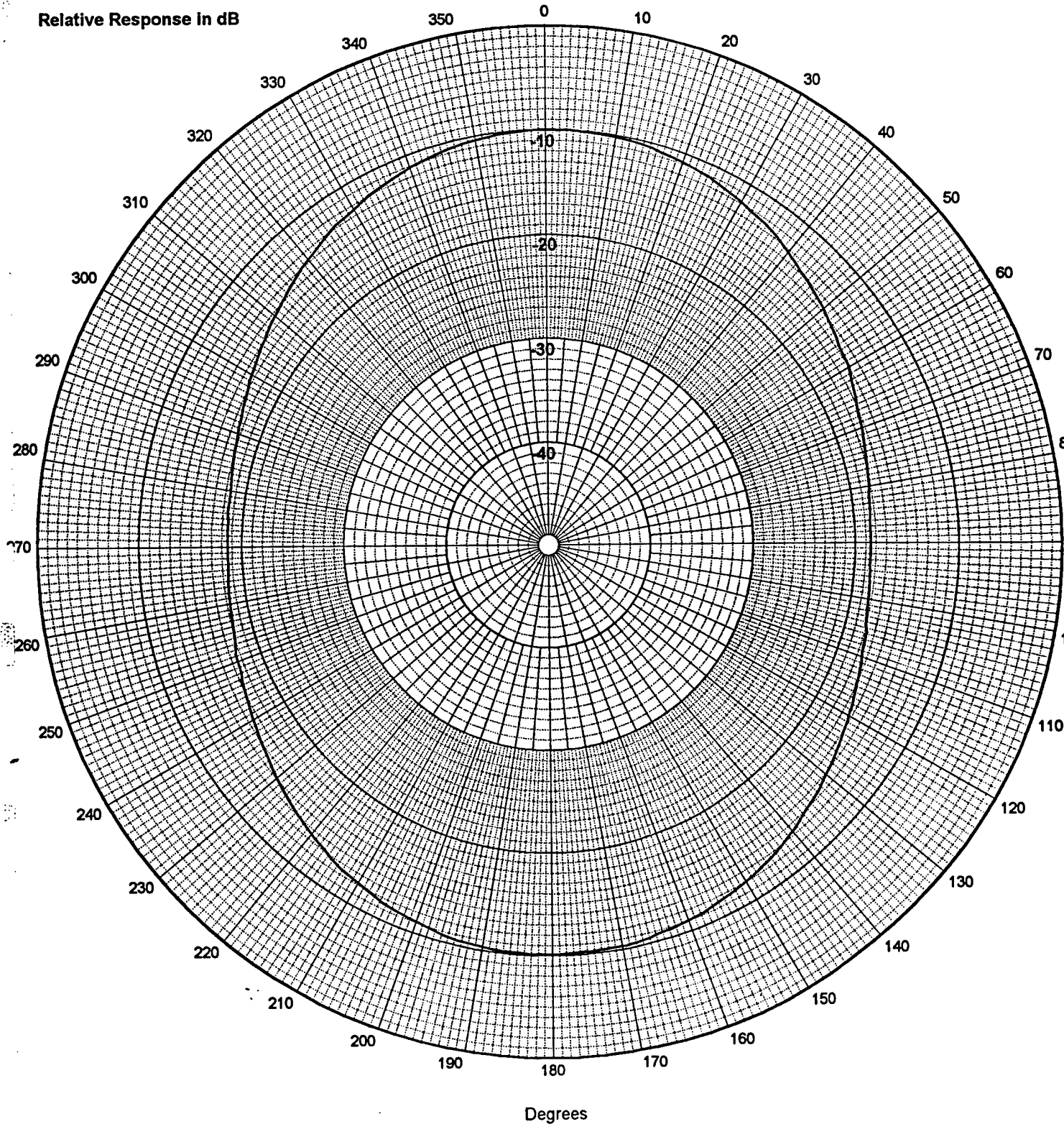
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

Water Temperature: 22° C

Transmit

XY Plane

10 kHz



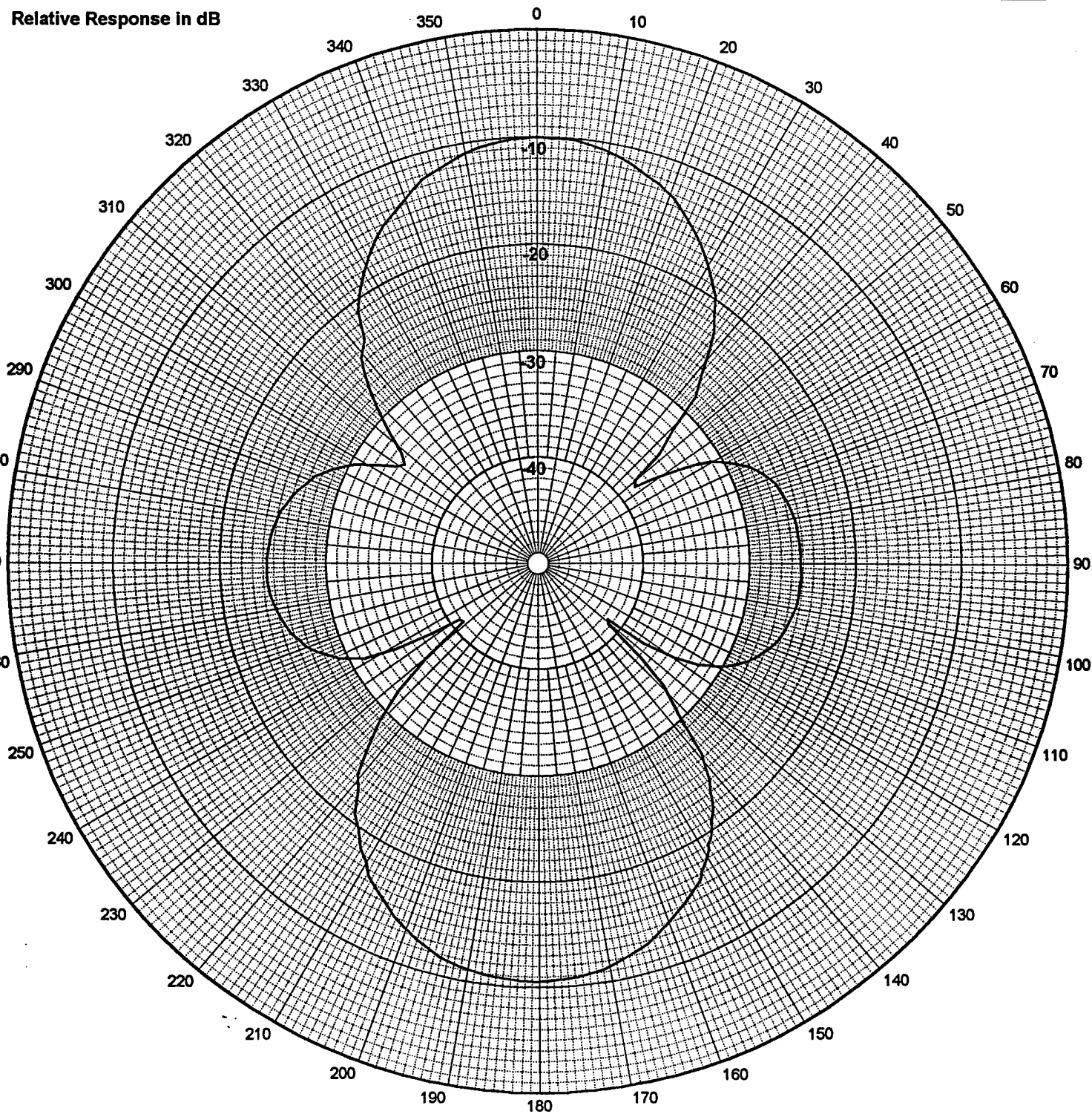
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB

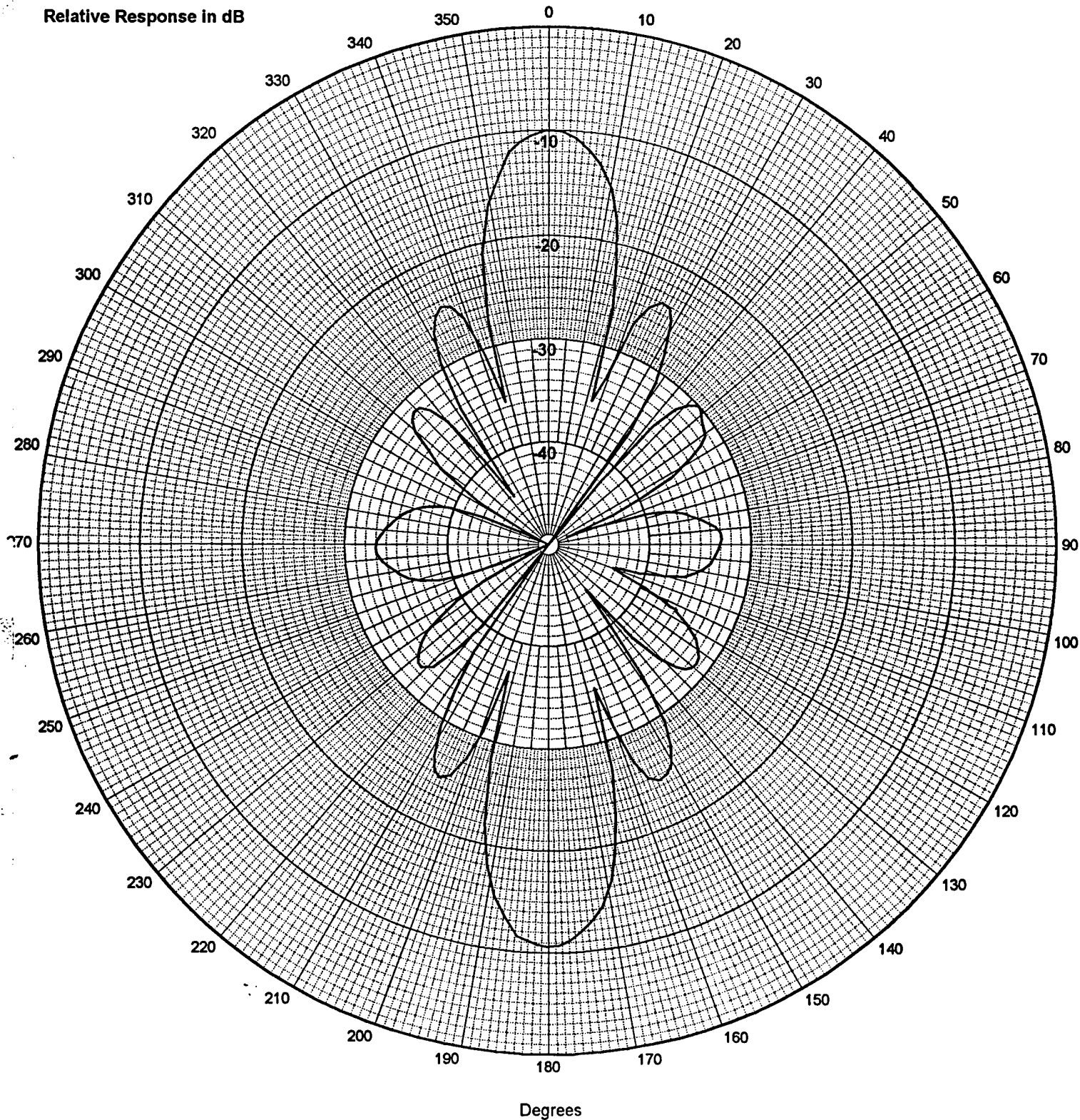


Degrees



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz





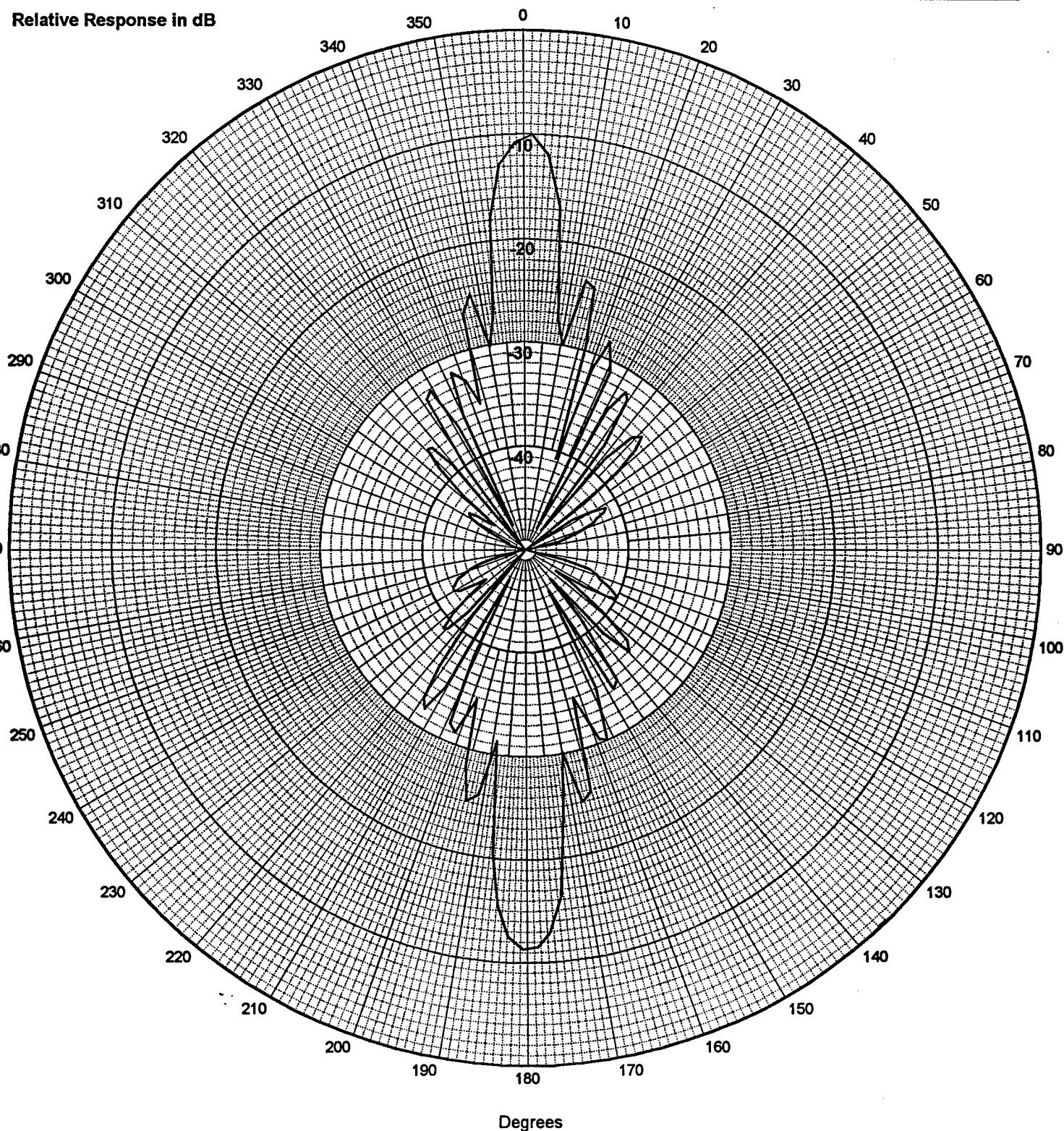
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-44  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



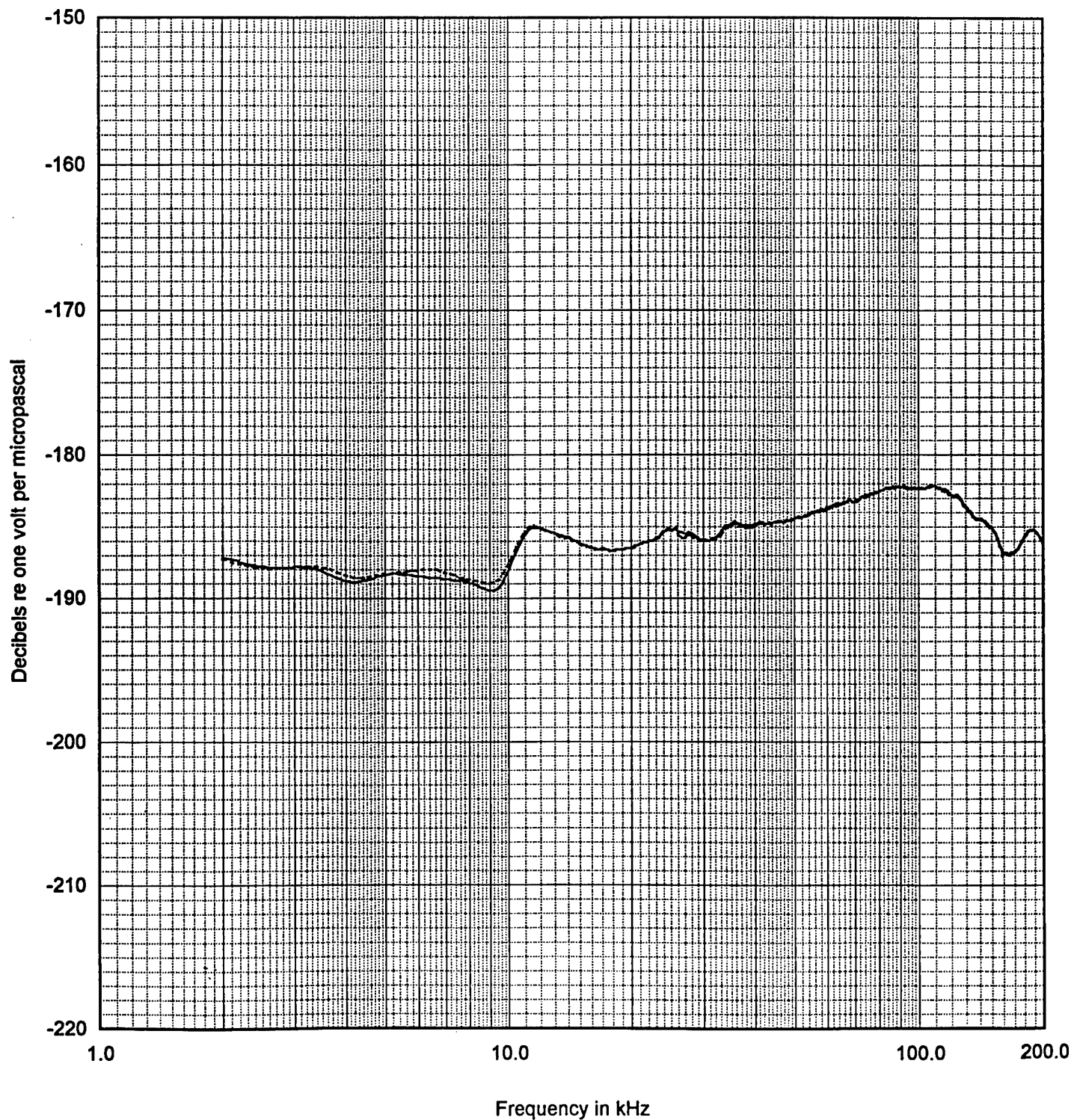
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-67

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m ) Before Pressure  
----- 16 kPa ( 1.6 m ) After Pressure



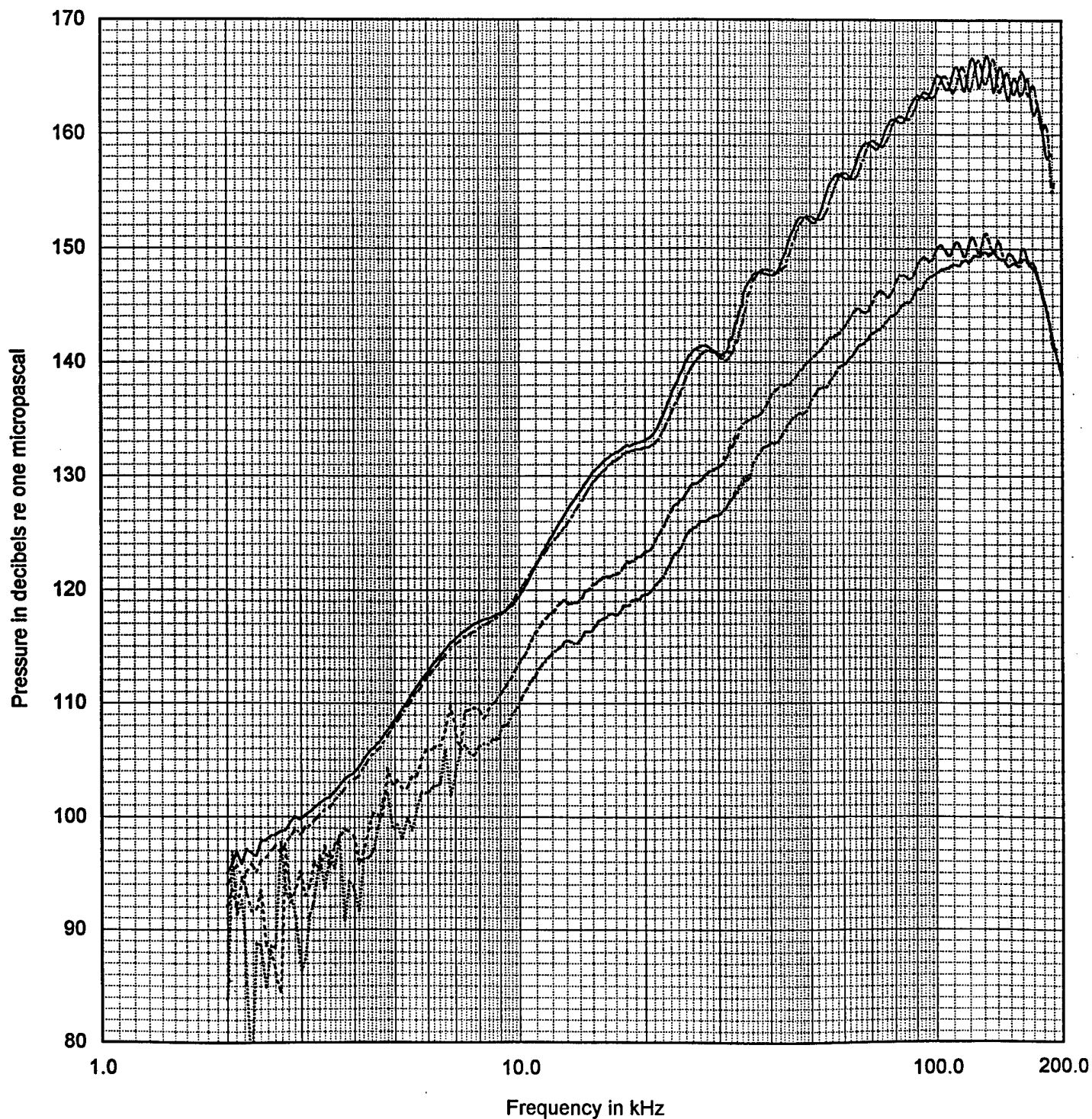
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-67

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

————— 16 kPa ( 1.6 m) Before Pressure  
- - - - - 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- . - . - 16 kPa ( 1.6 m) After Pressure



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

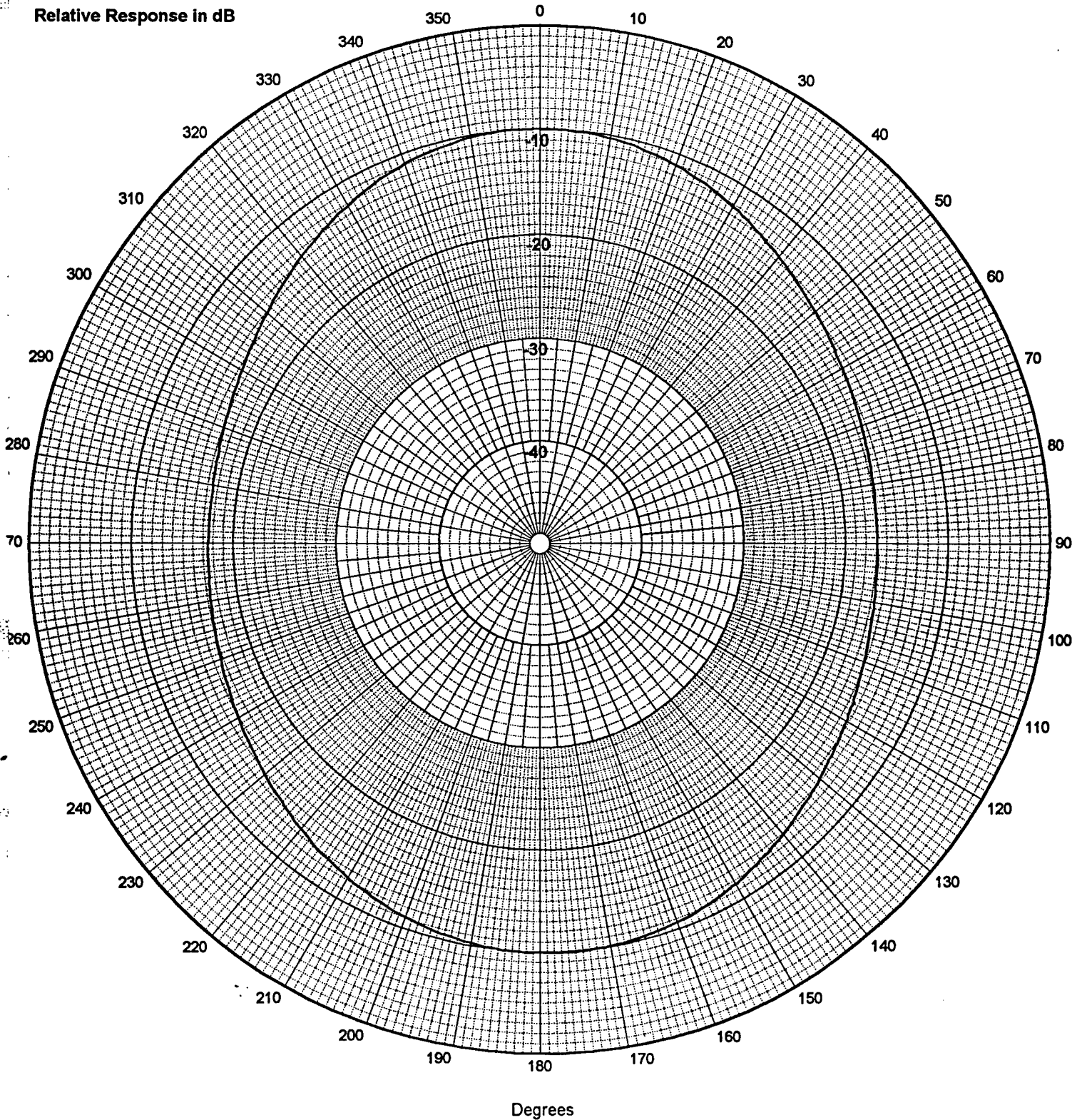
Water Temperature: 4° C

Transmit

XY Plane

10 kHz

Relative Response in dB





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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

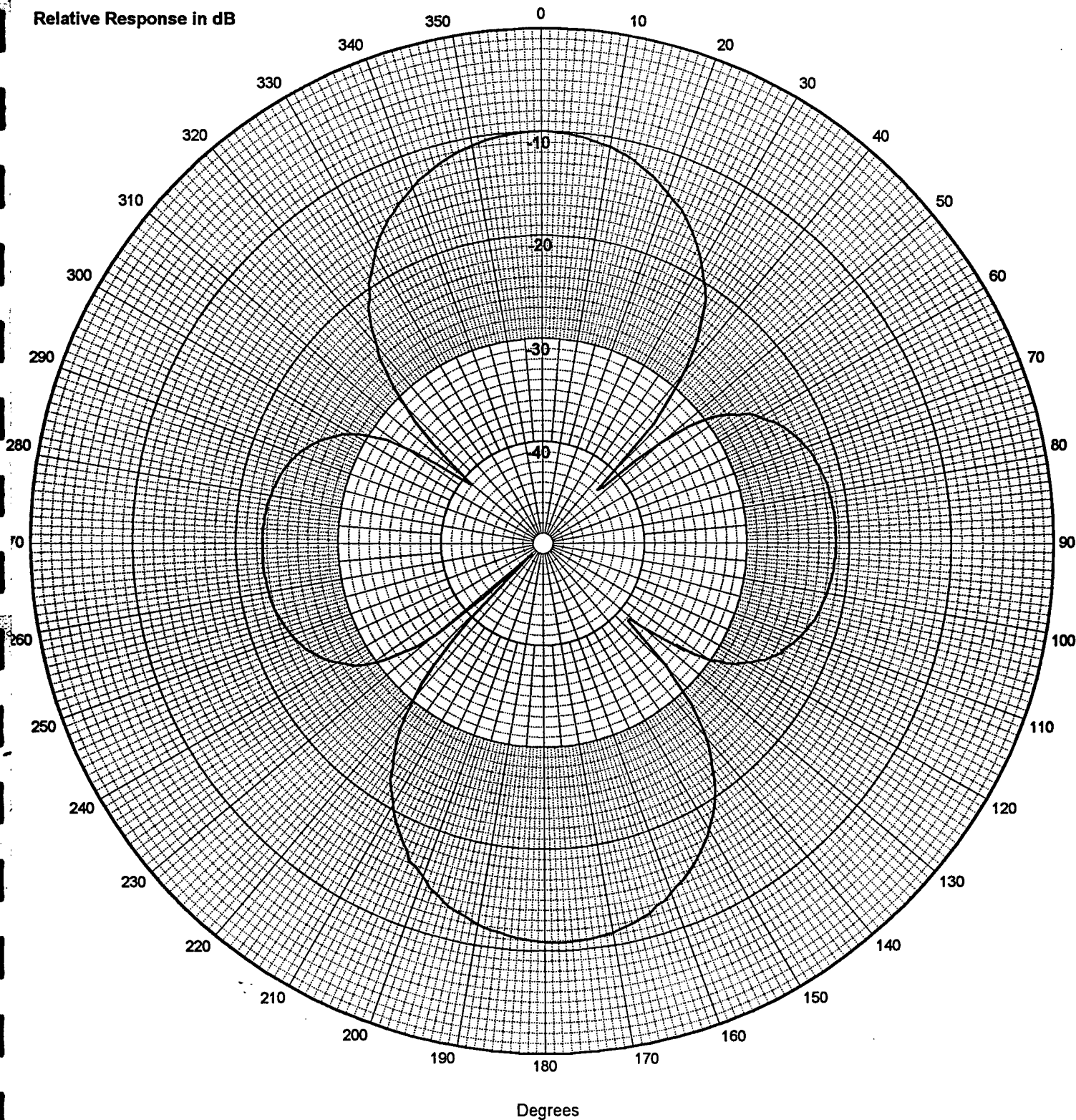
Water Temperature: 4° C

Transmit

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

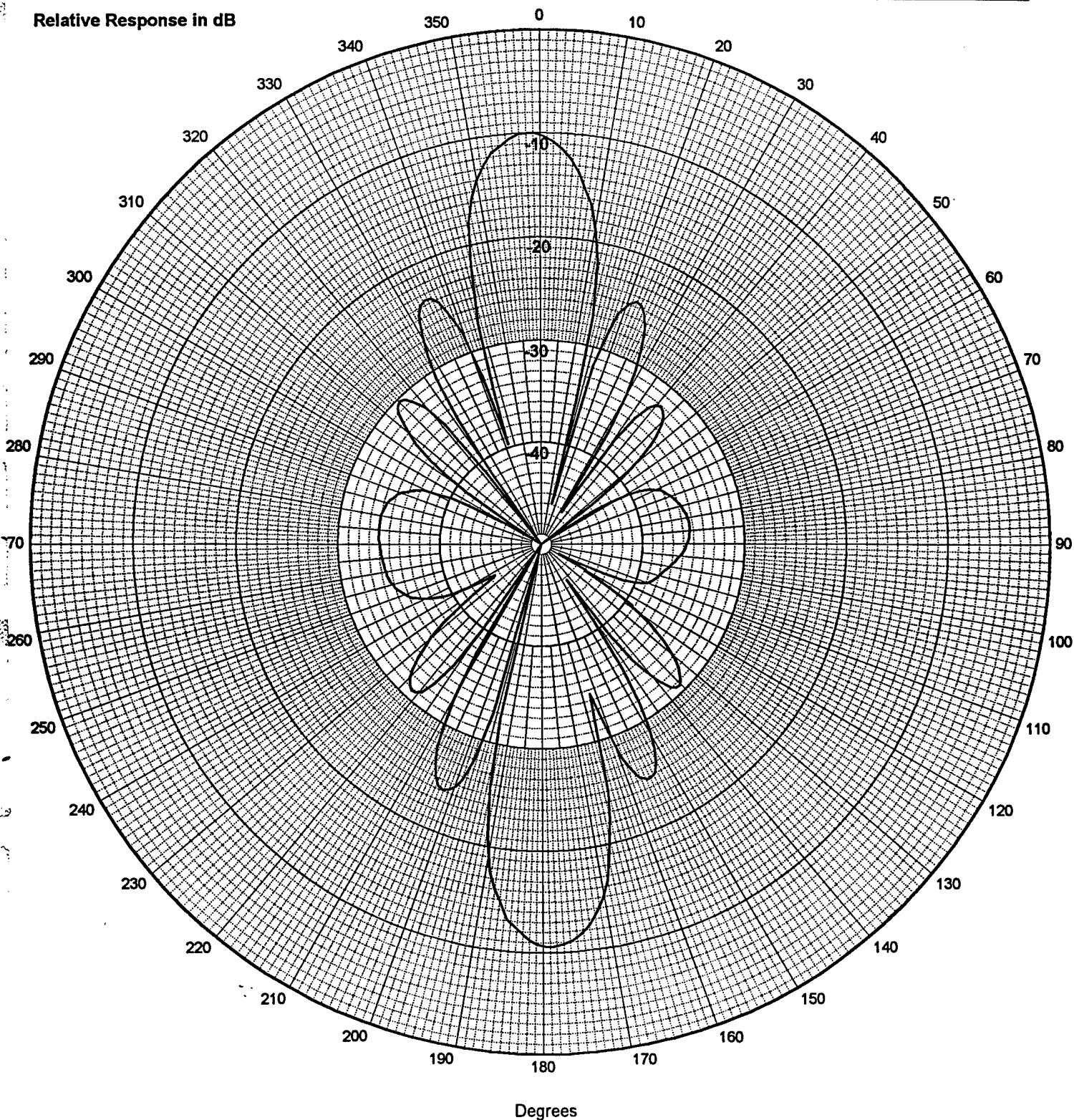
Water Temperature: 4° C

Transmit

XY Plane

50 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

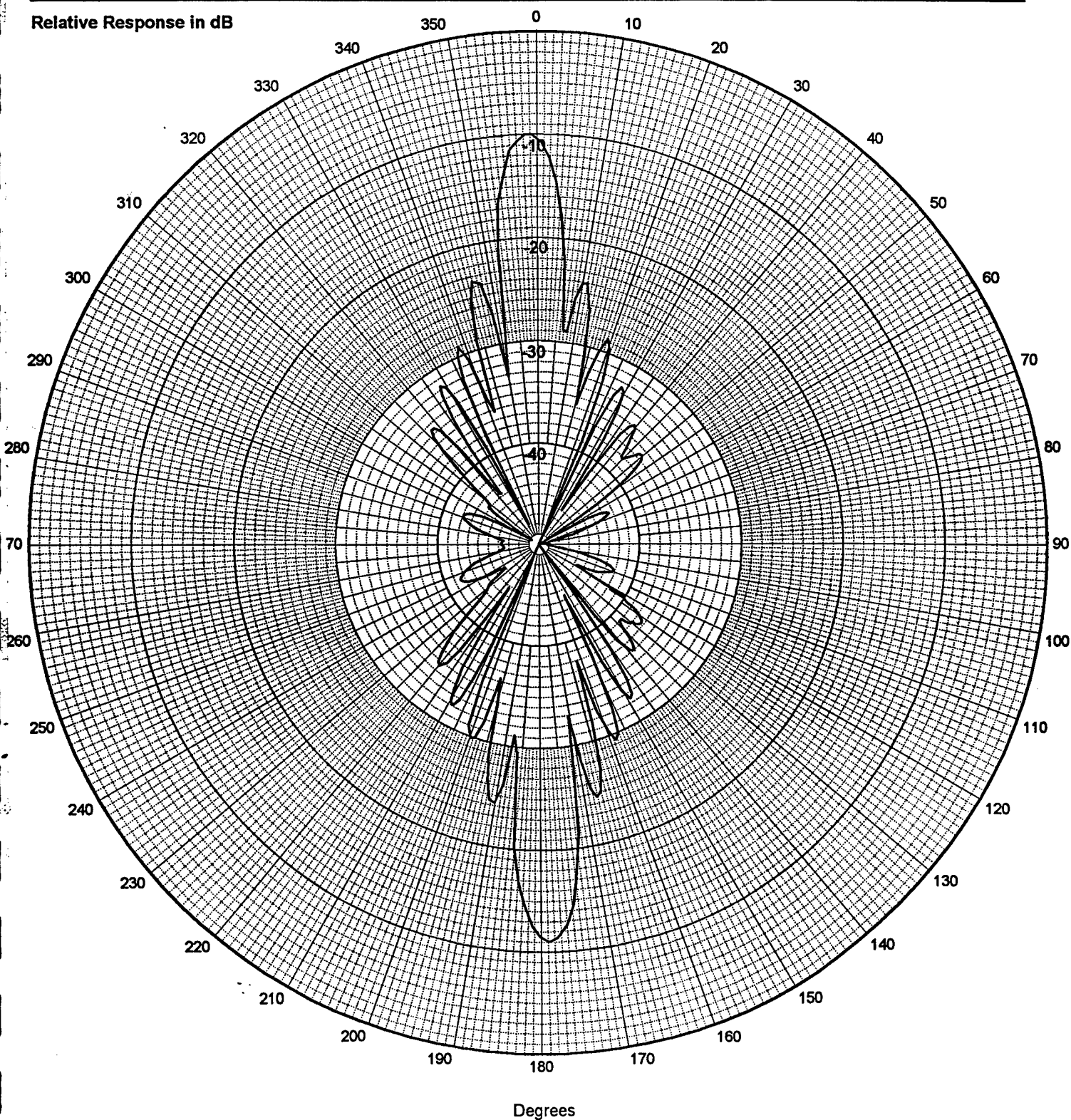
Water Temperature: 4° C

Transmit

XY Plane

100 kHz

Relative Response in dB



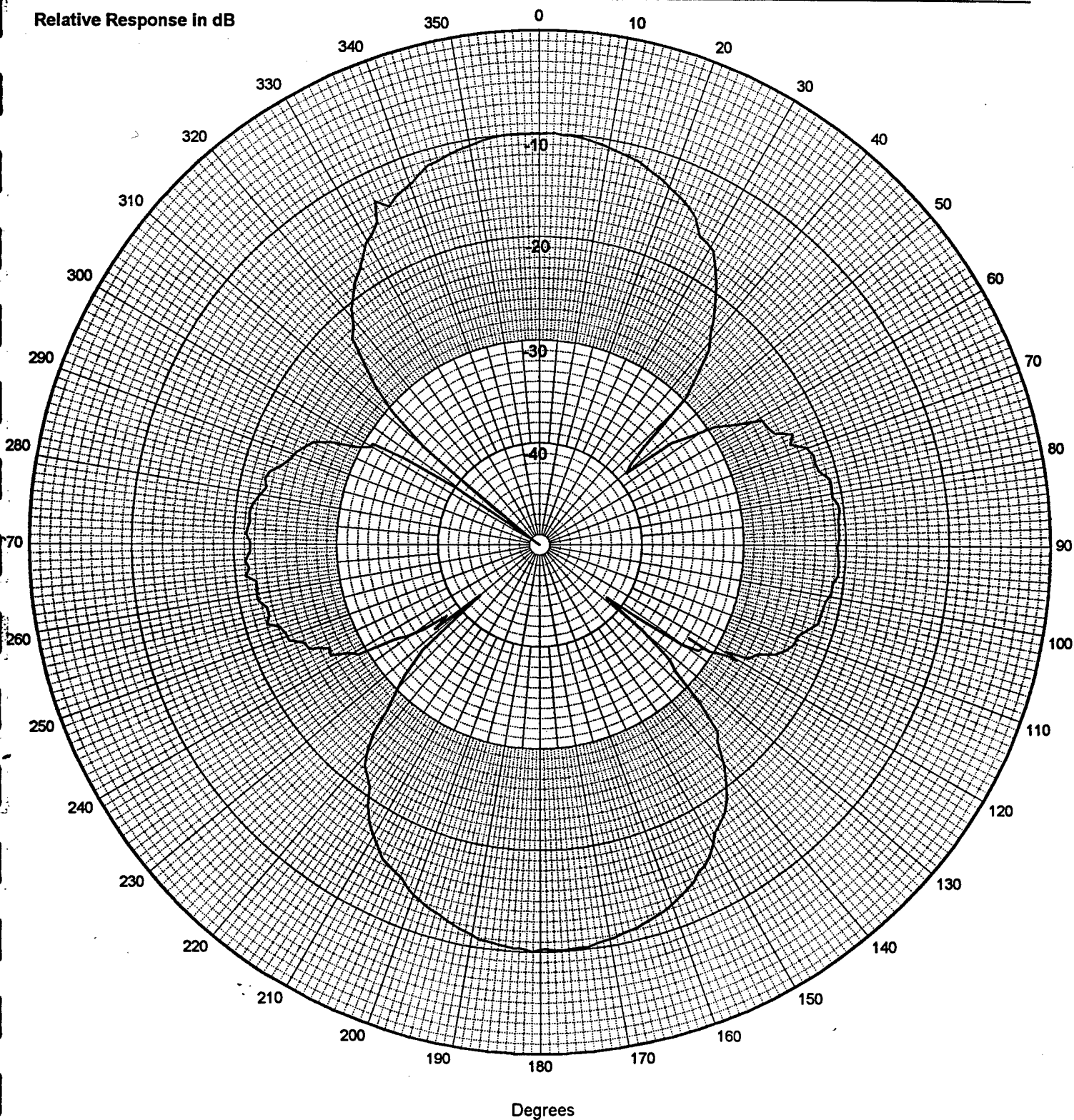
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
20 kHz

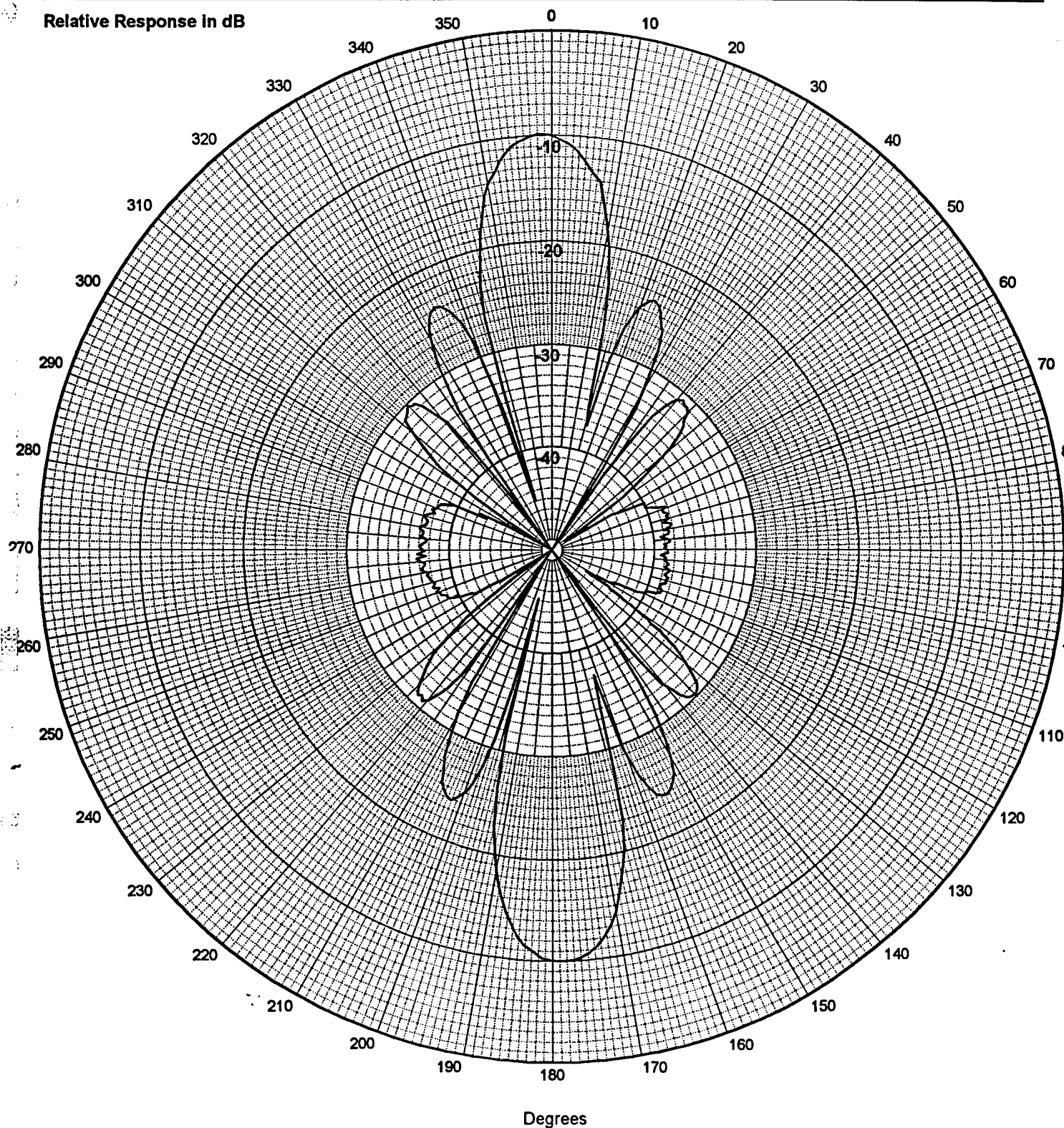
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
50 kHz



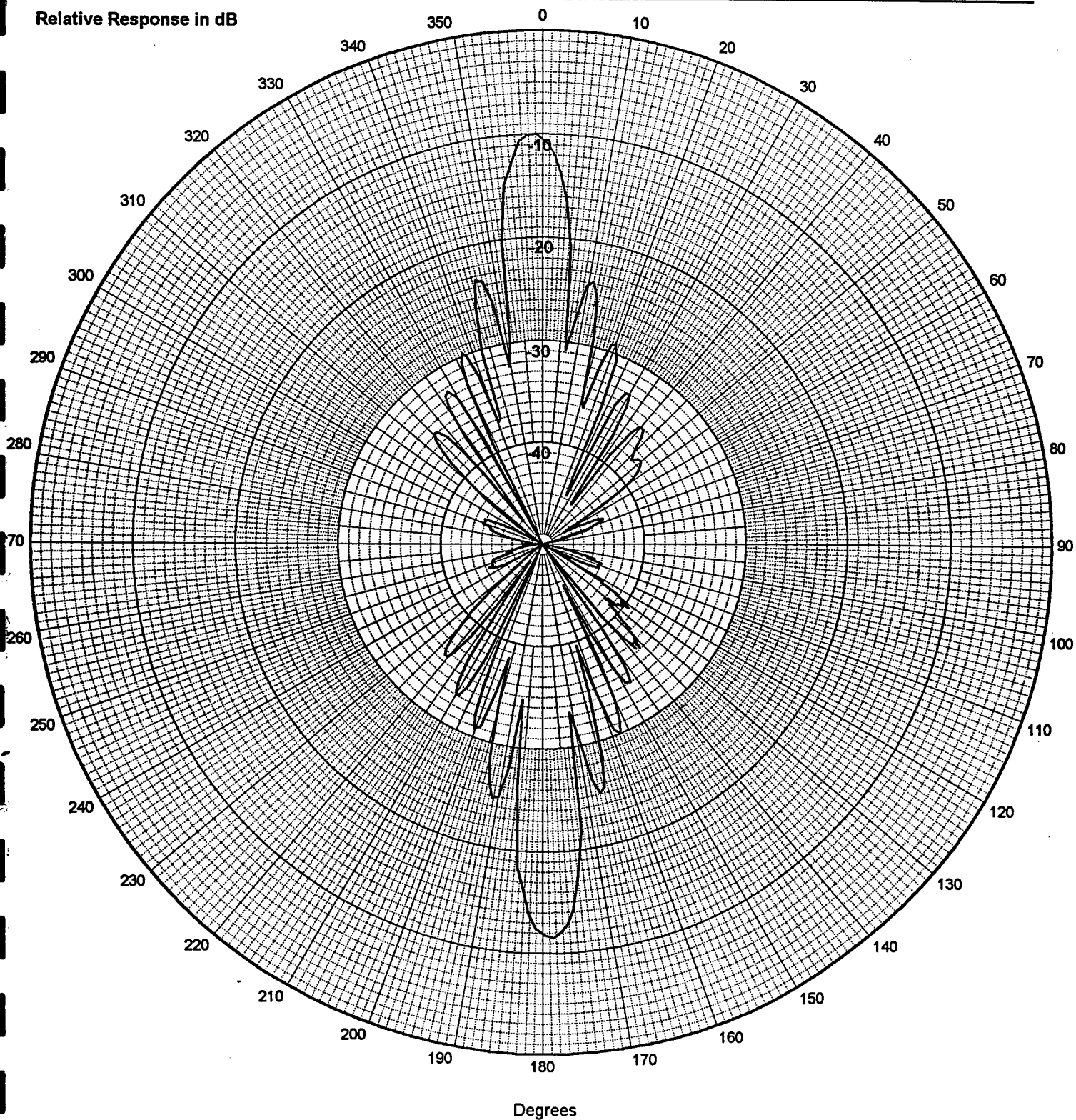
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz

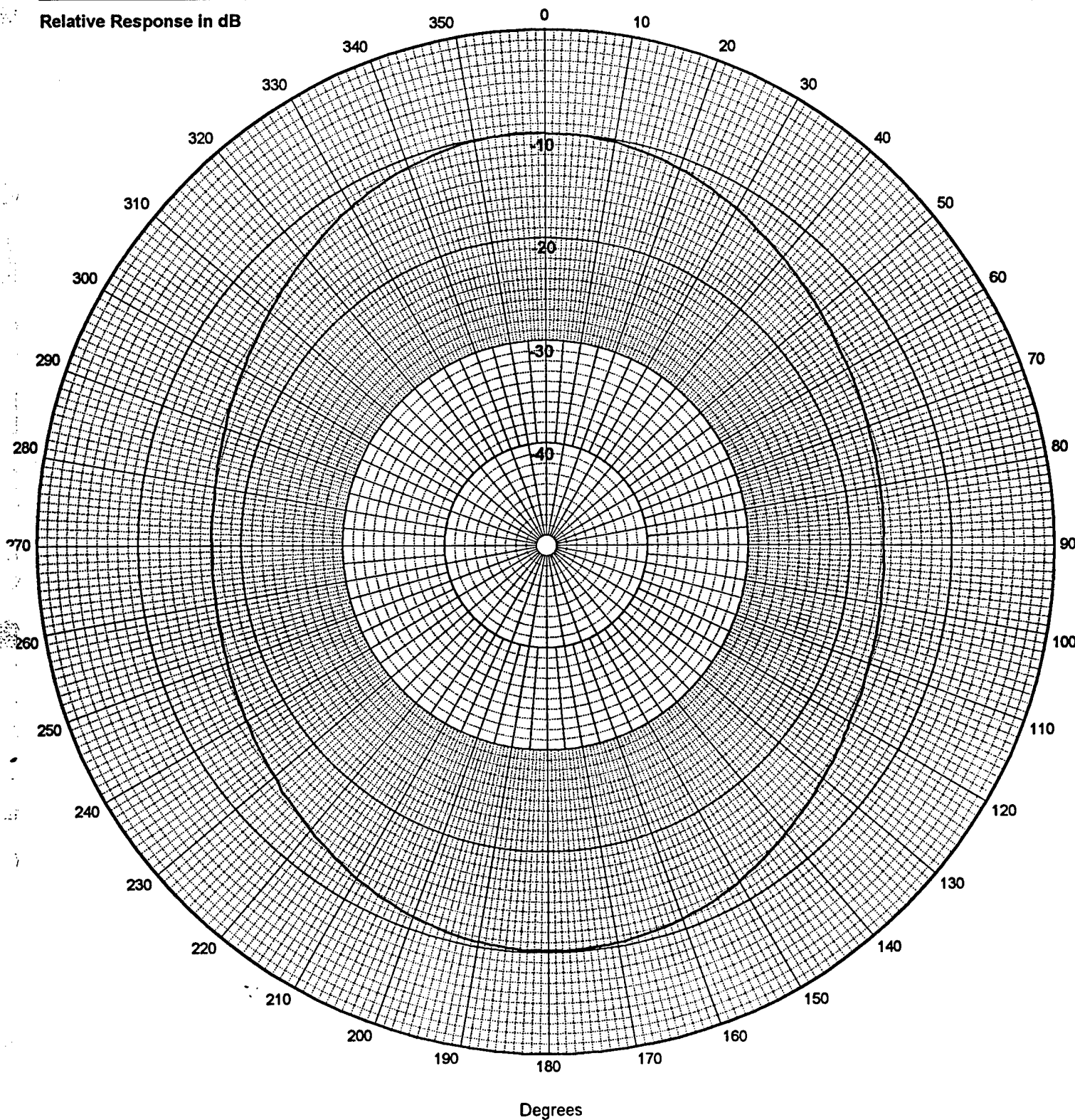
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB



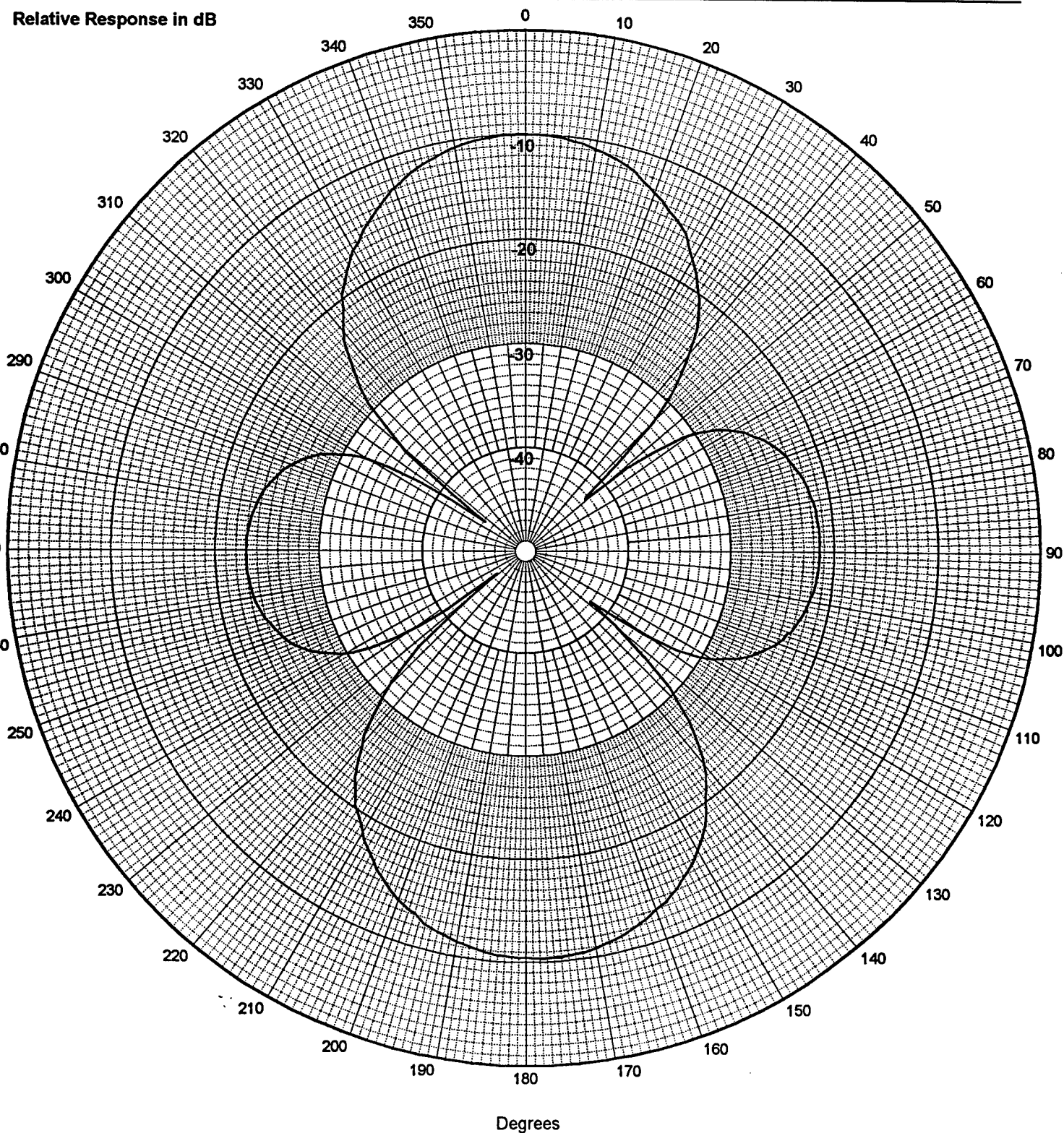
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
20 kHz

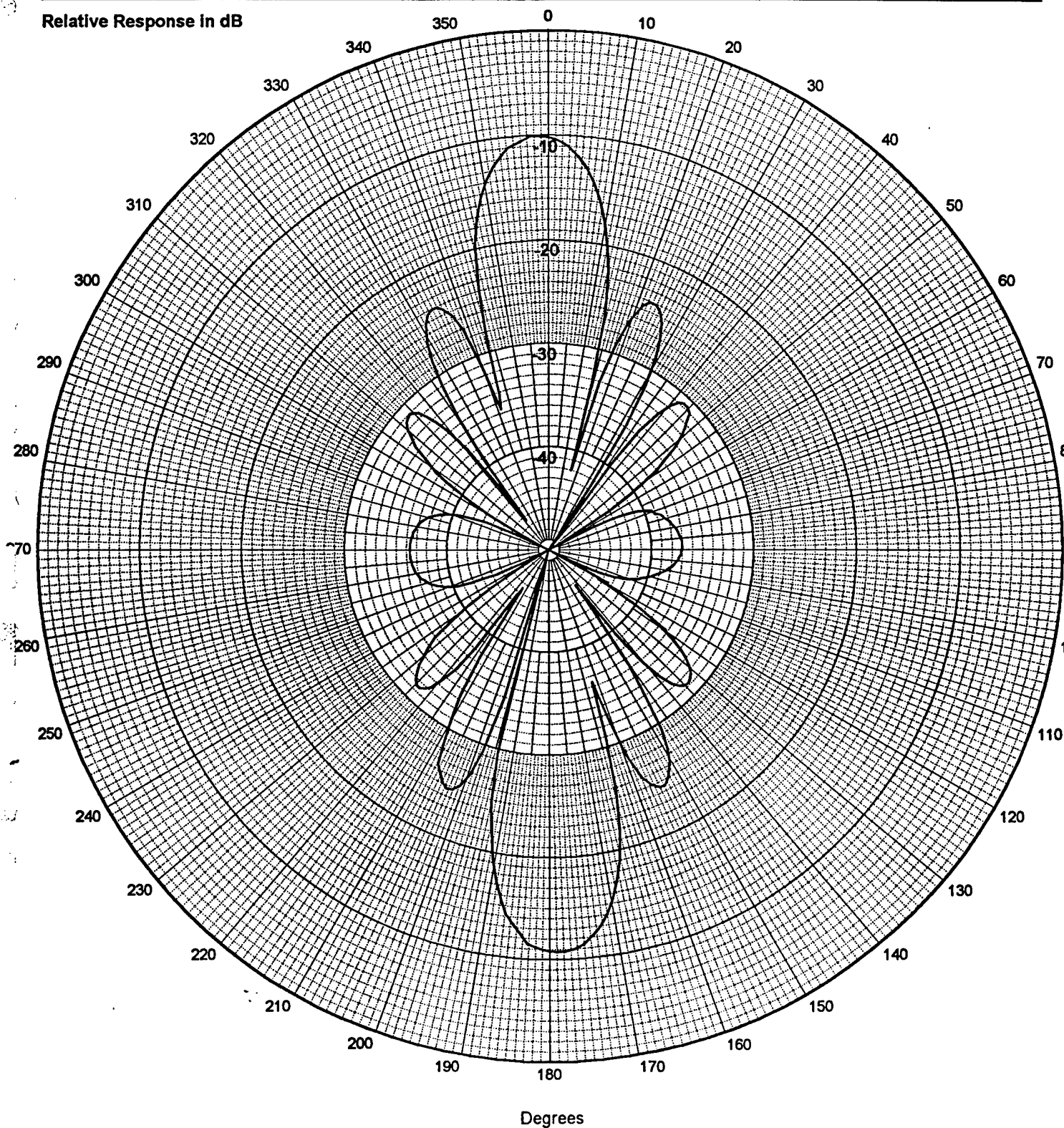
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
50 kHz



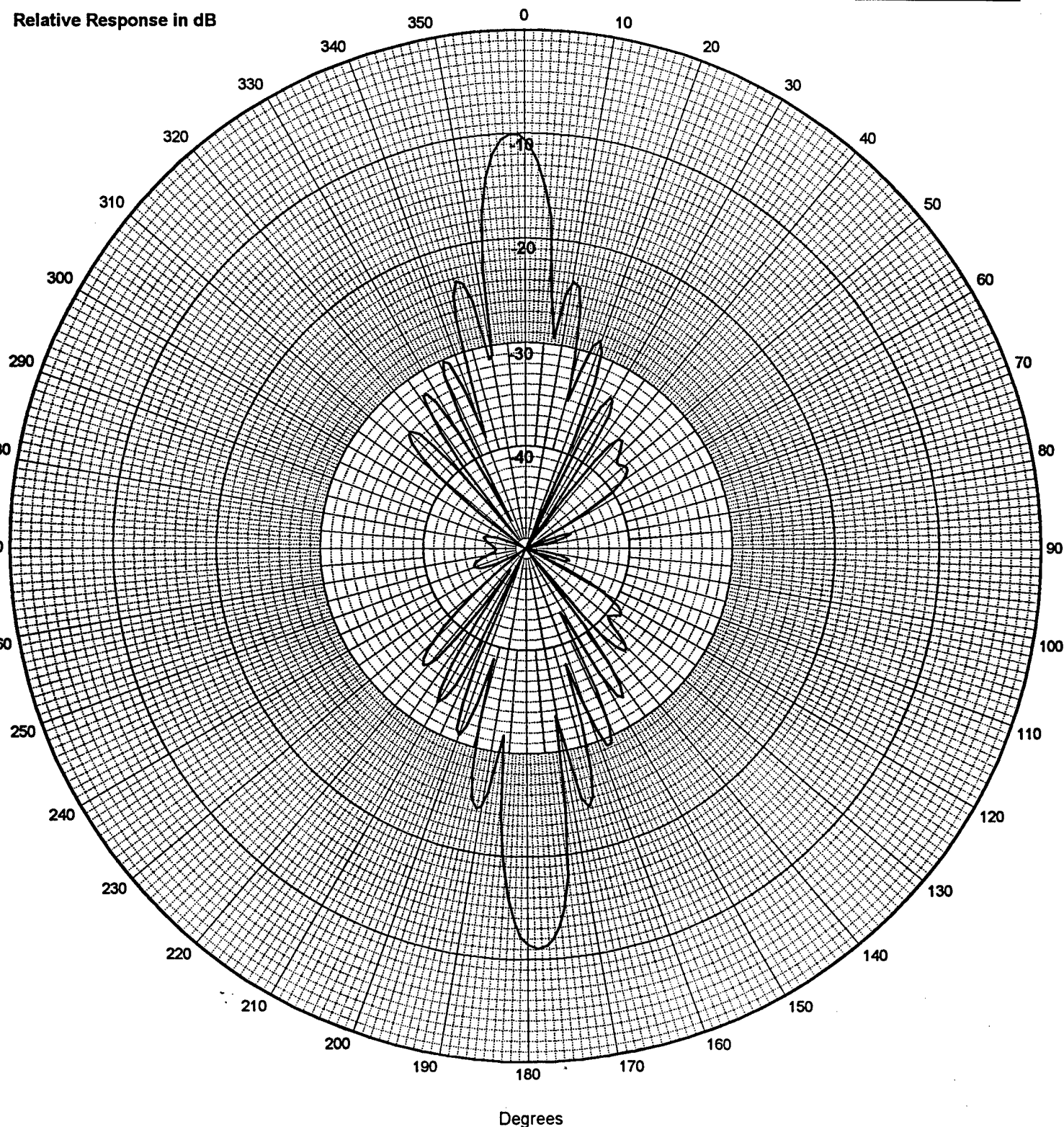
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



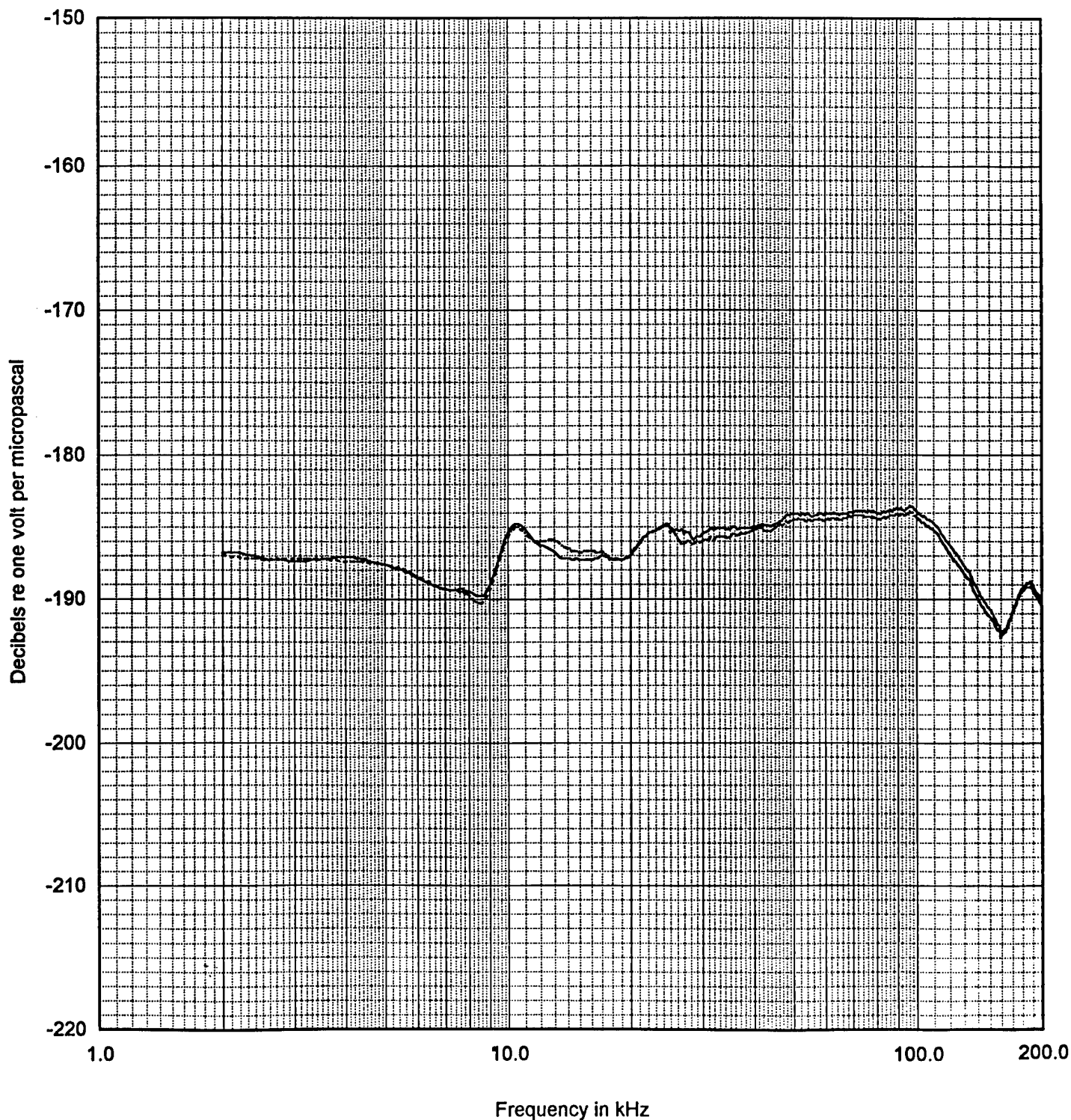
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-67

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m ) Before Pressure  
----- 16 kPa ( 1.6 m ) After Pressure



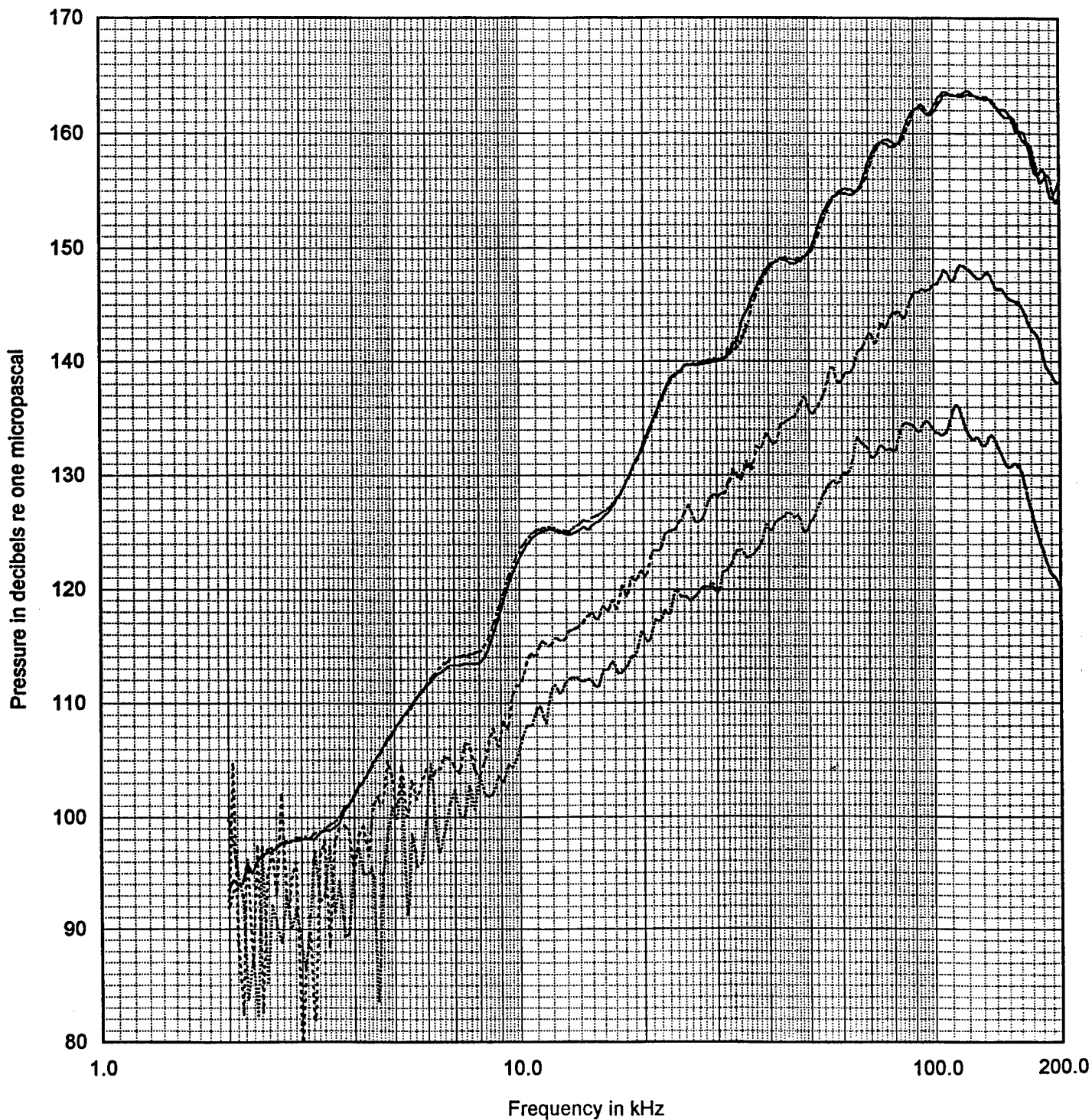
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-67

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

— 16 kPa ( 1.6 m) Before Pressure  
- - - 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- . - . 16 kPa ( 1.6 m) After Pressure





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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

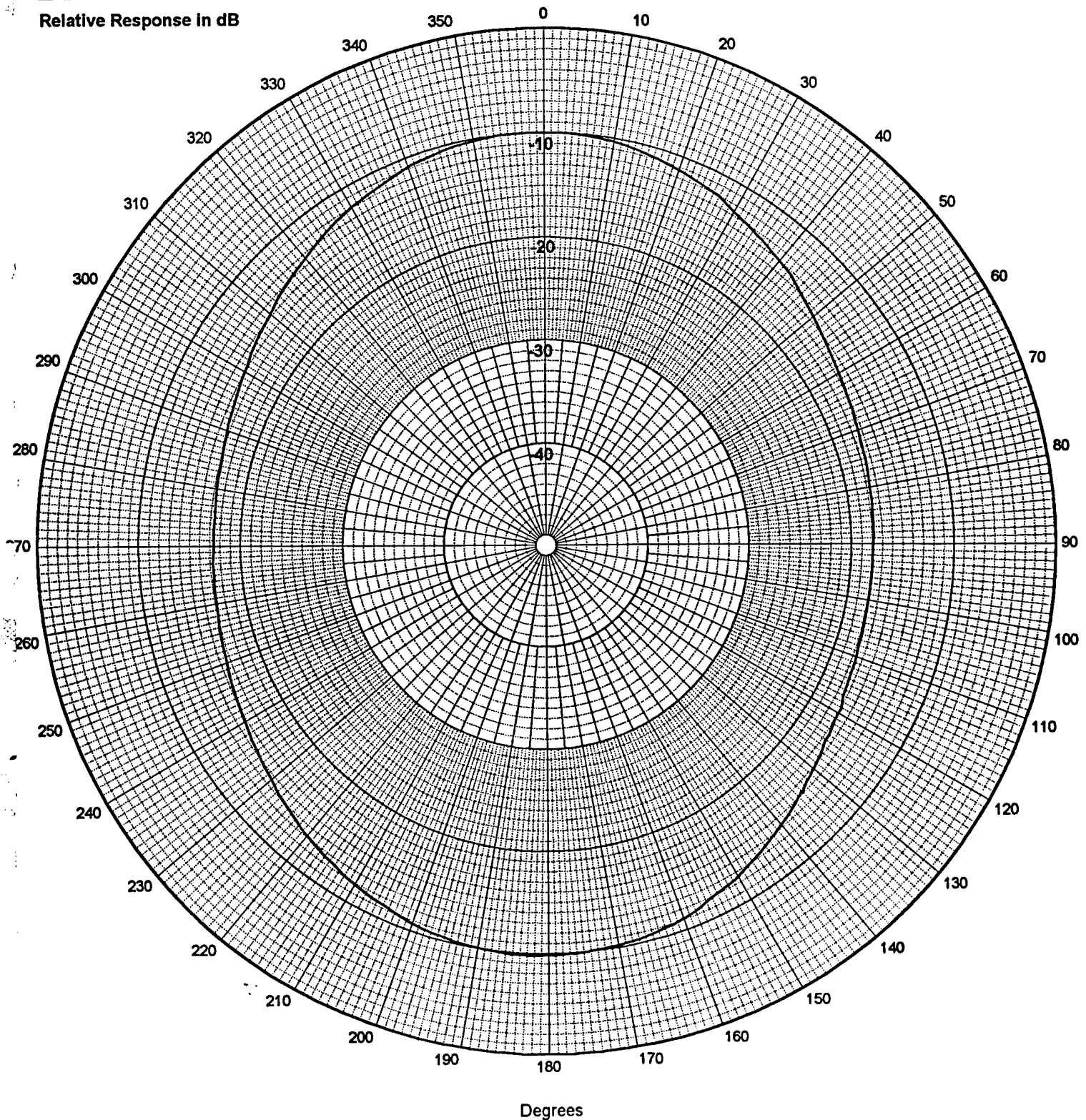
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

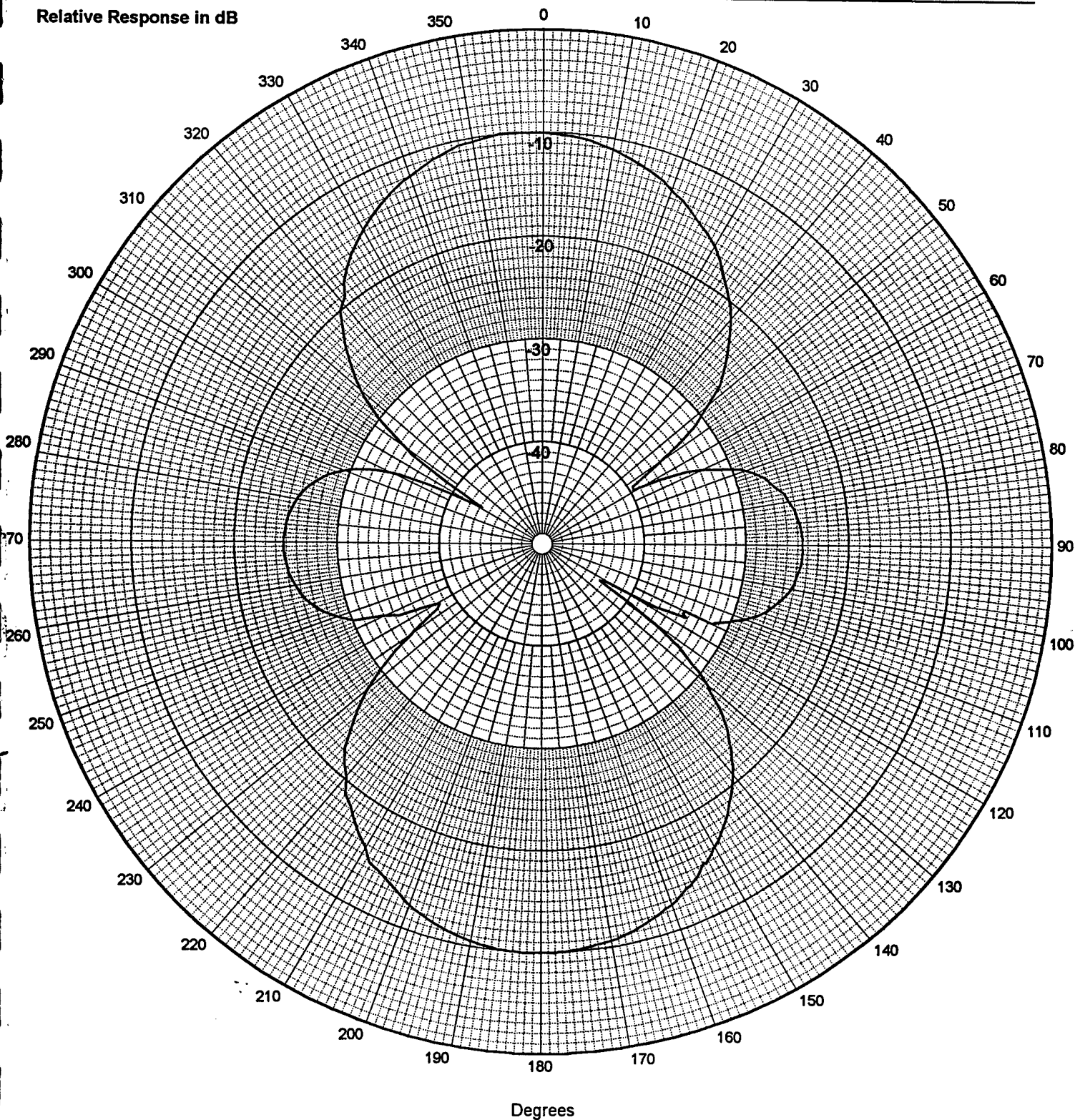
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

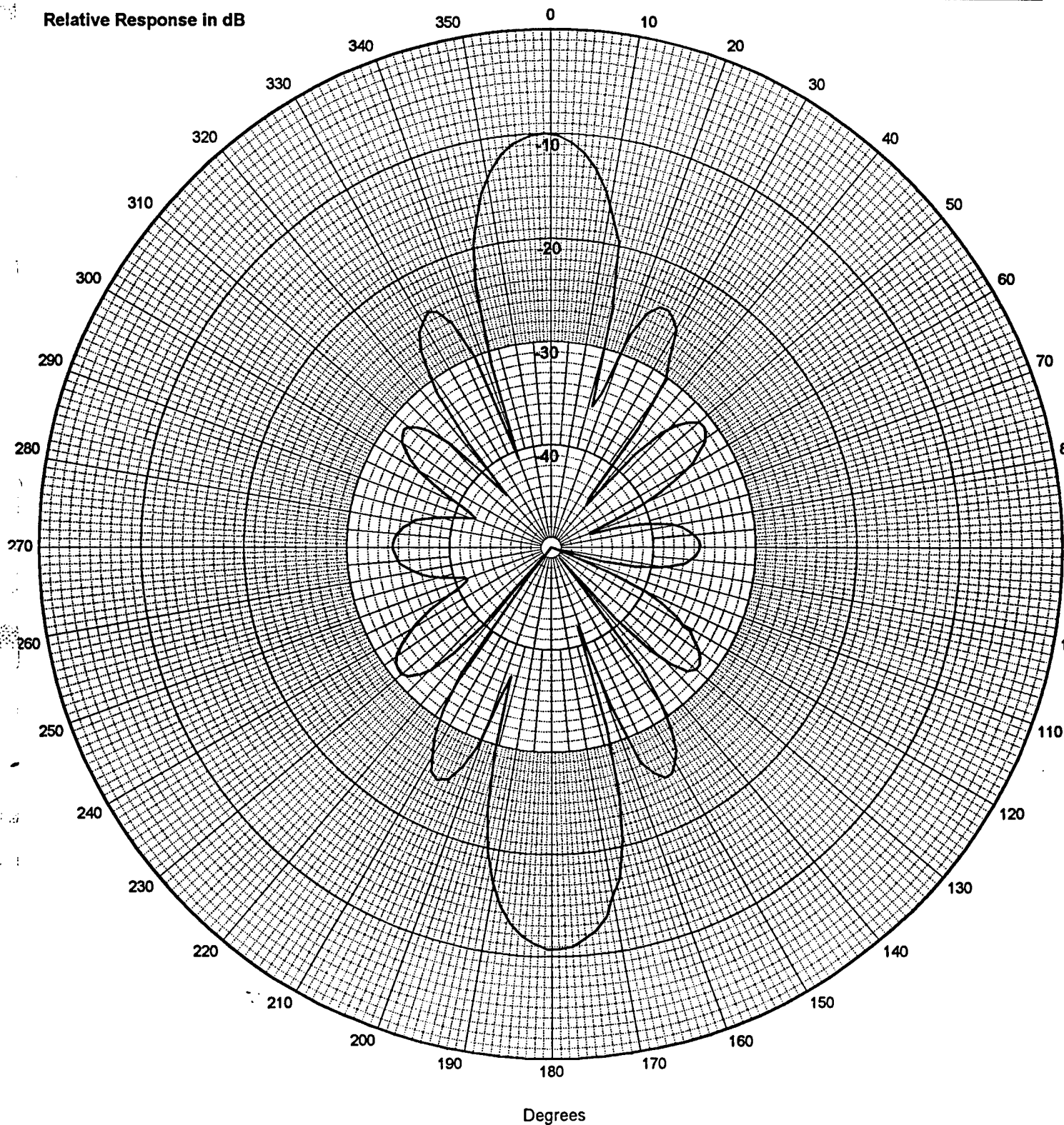
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



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USRD NO. 0779-49  
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

Hydrostatic Pressure: 16 kPa ( 1.6 m )

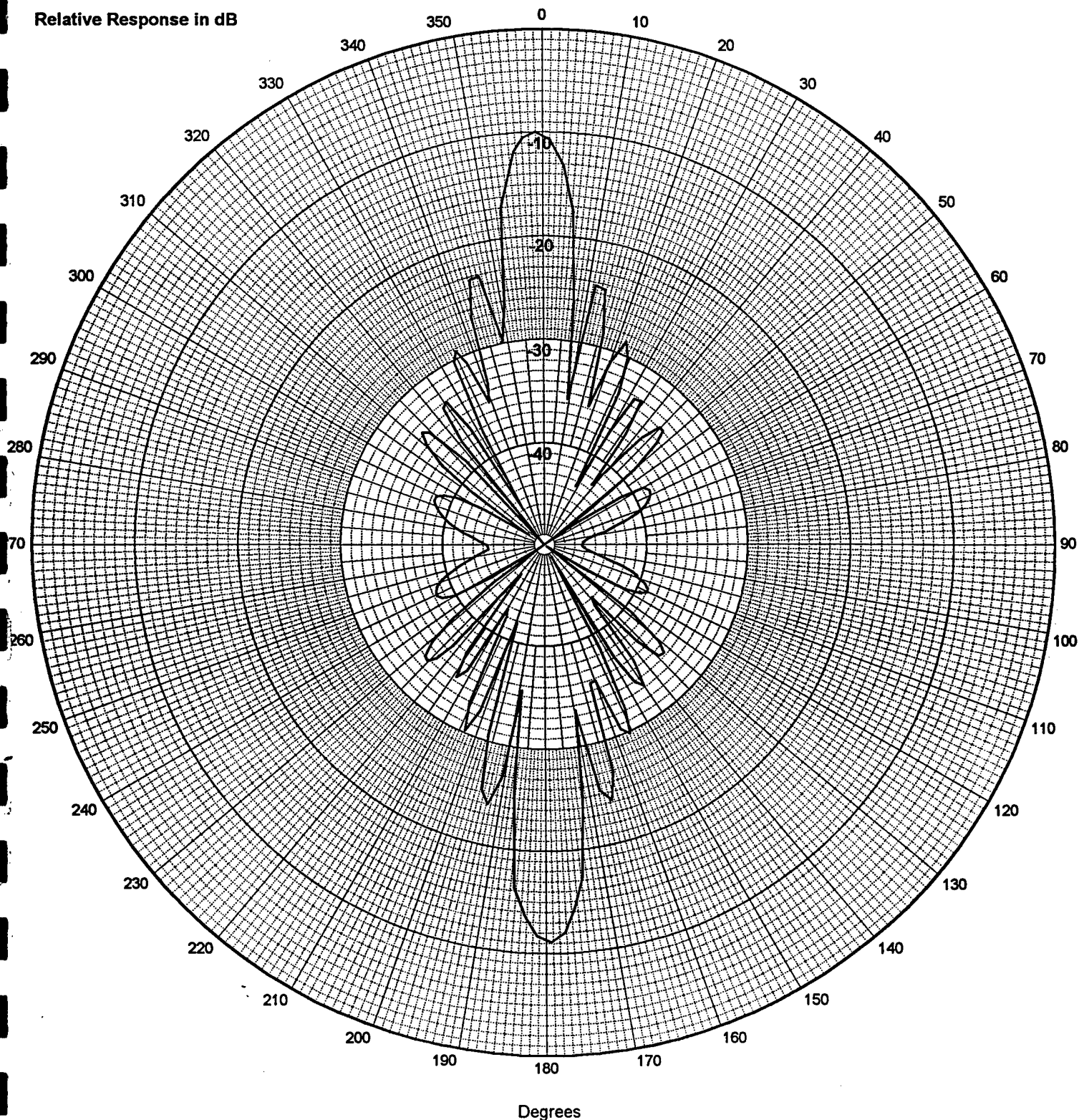
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

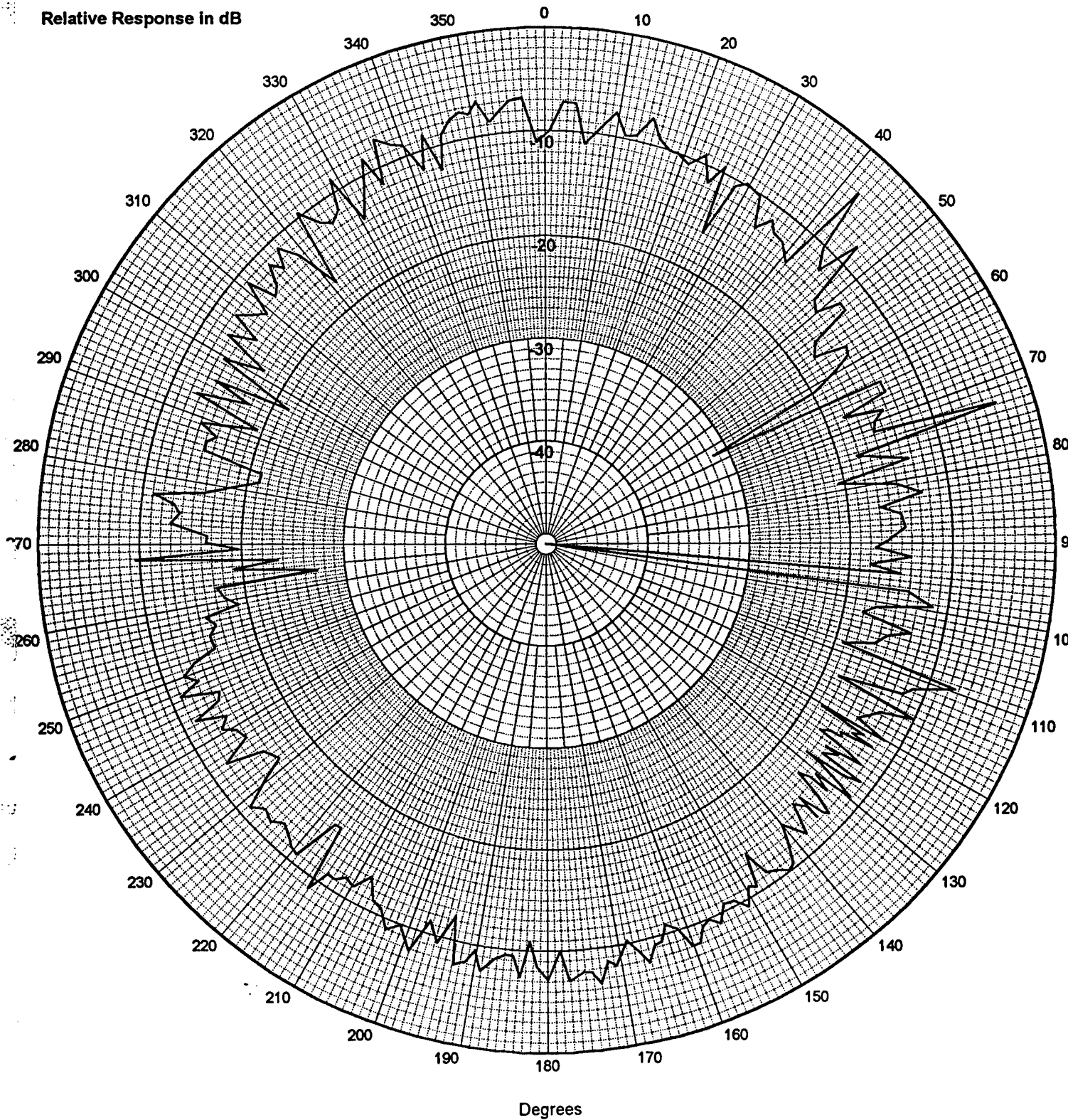
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz



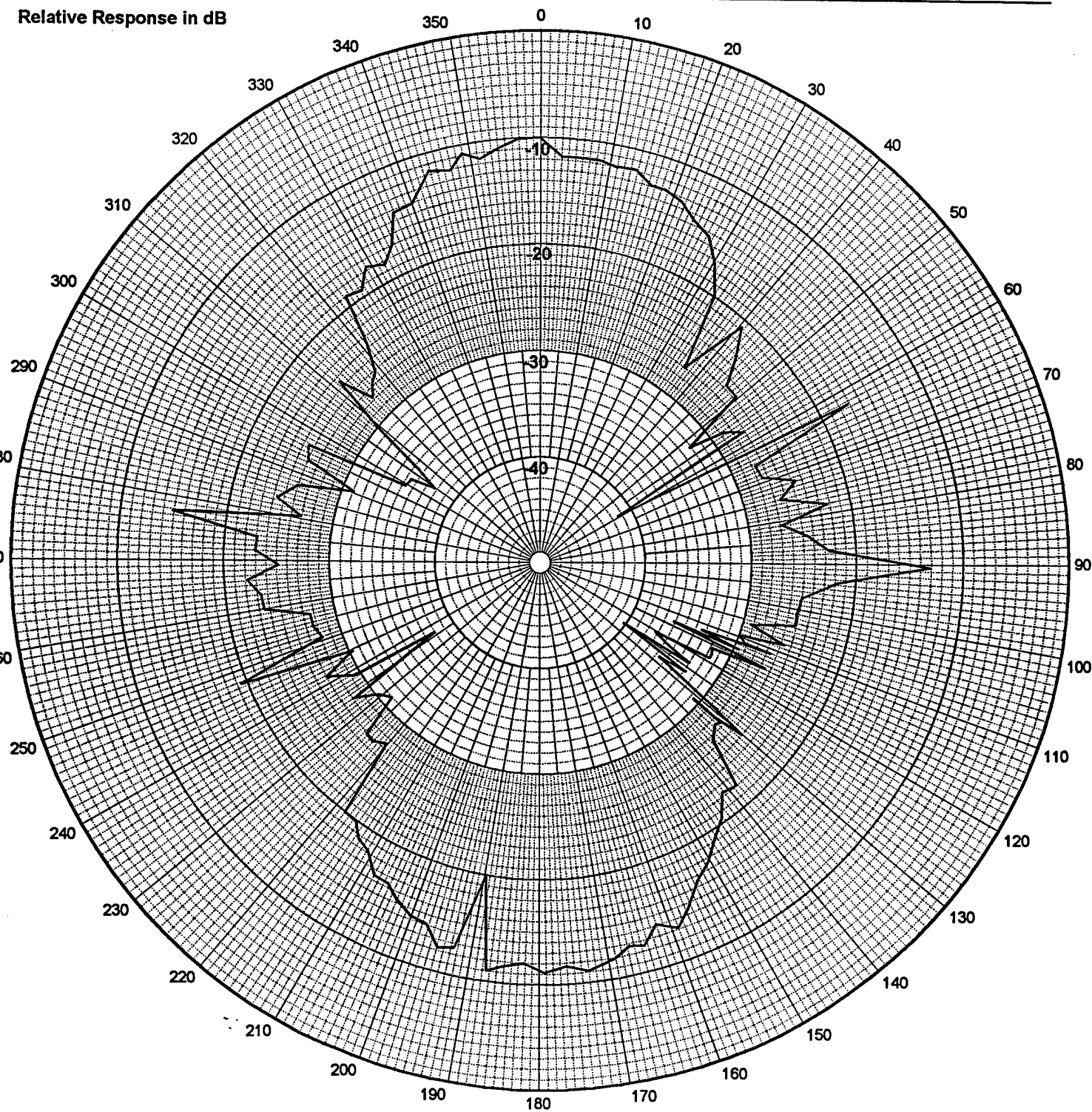
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

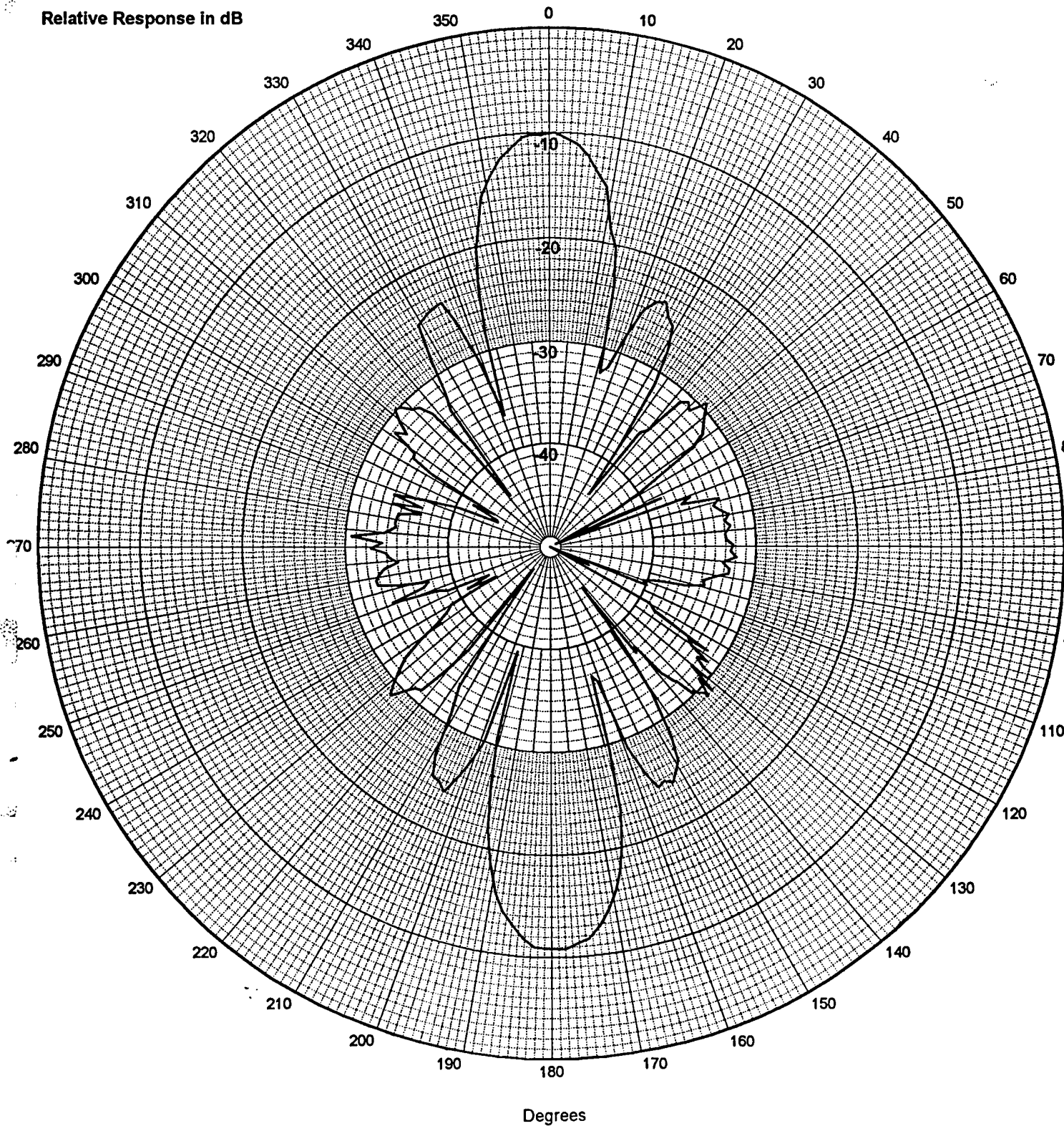
Relative Response in dB



Degrees

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz



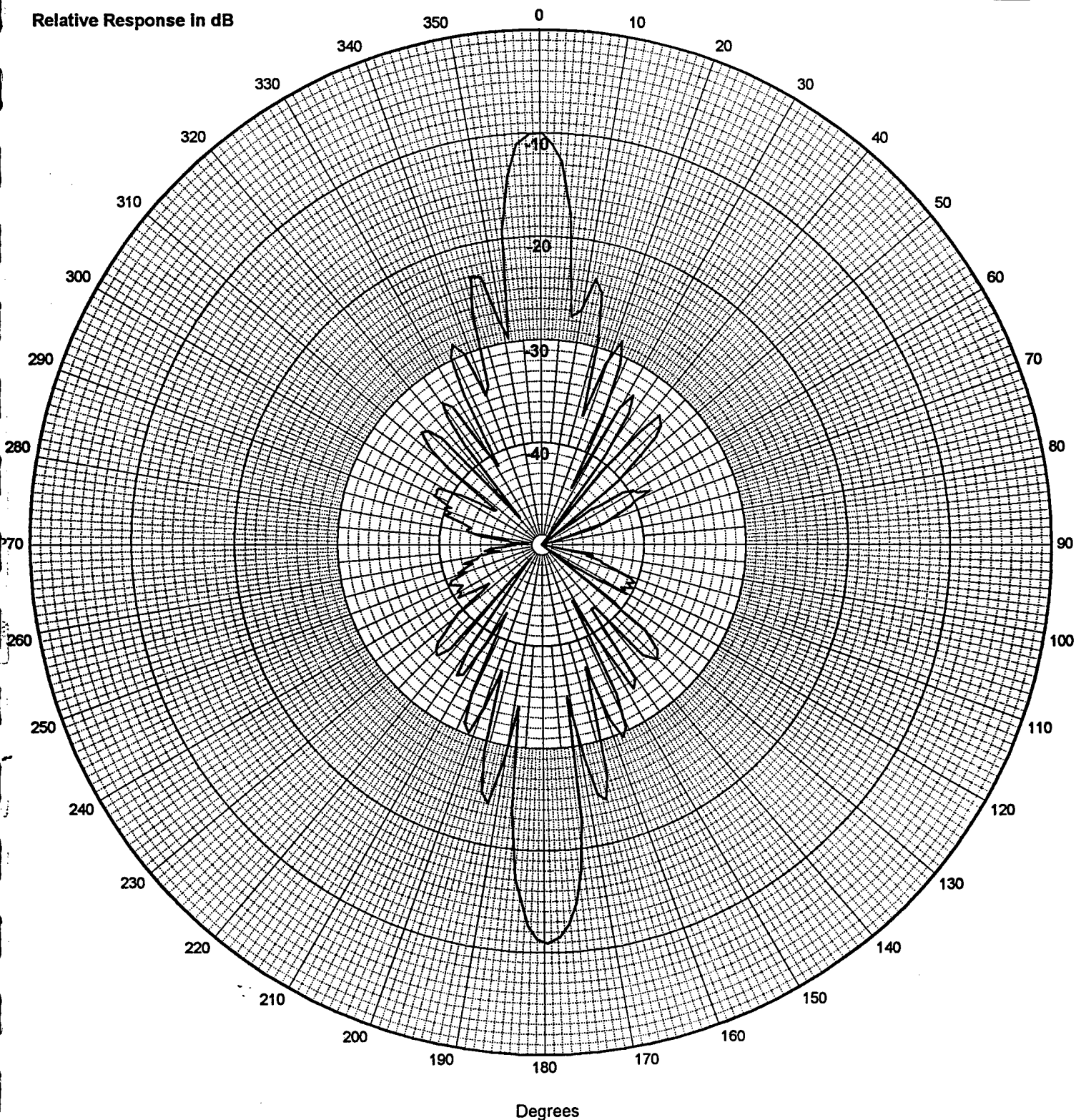
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB





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USRD NO. 0779-54  
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67

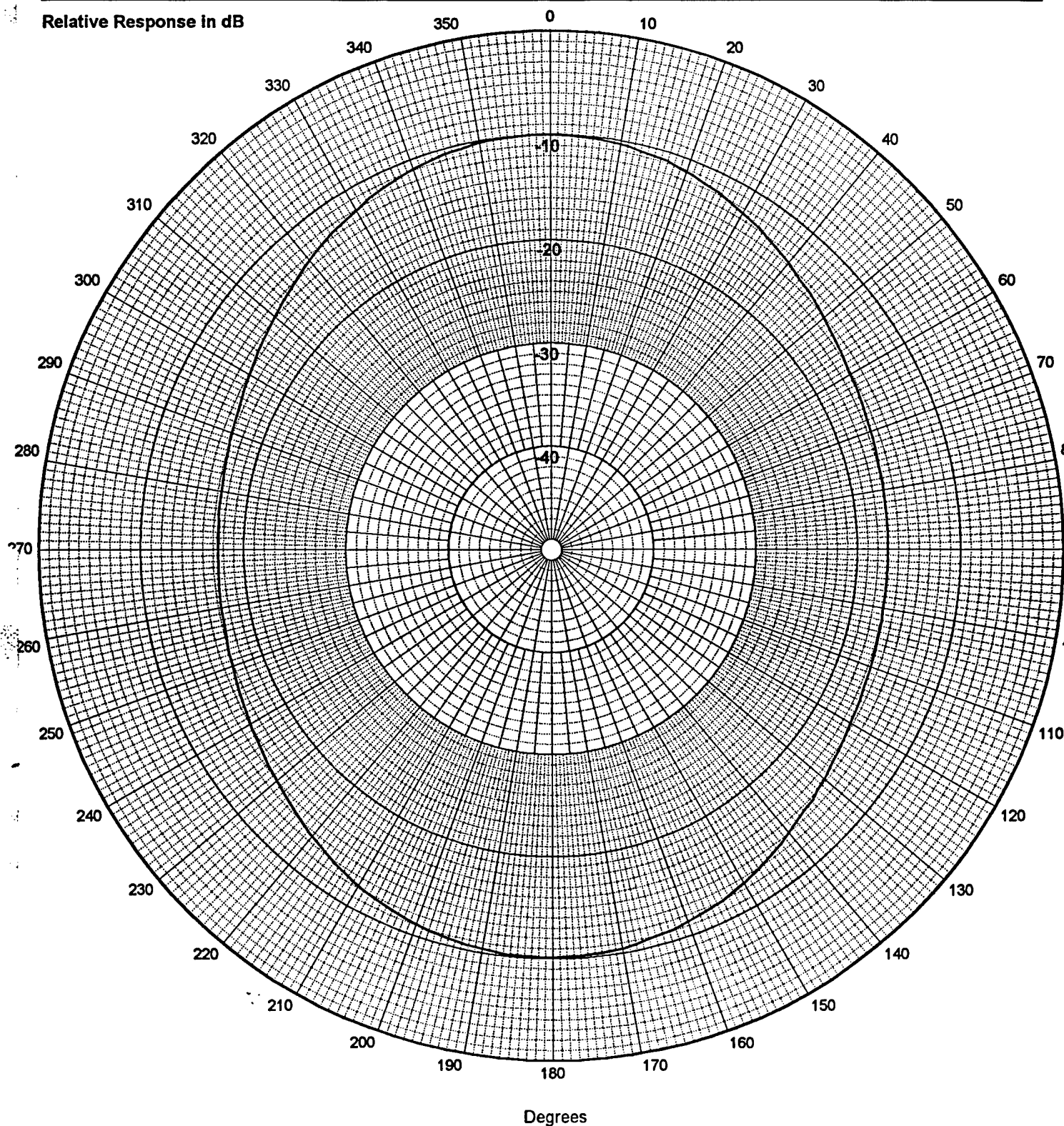
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

Water Temperature: 22° C

Transmit

XY Plane

10 kHz



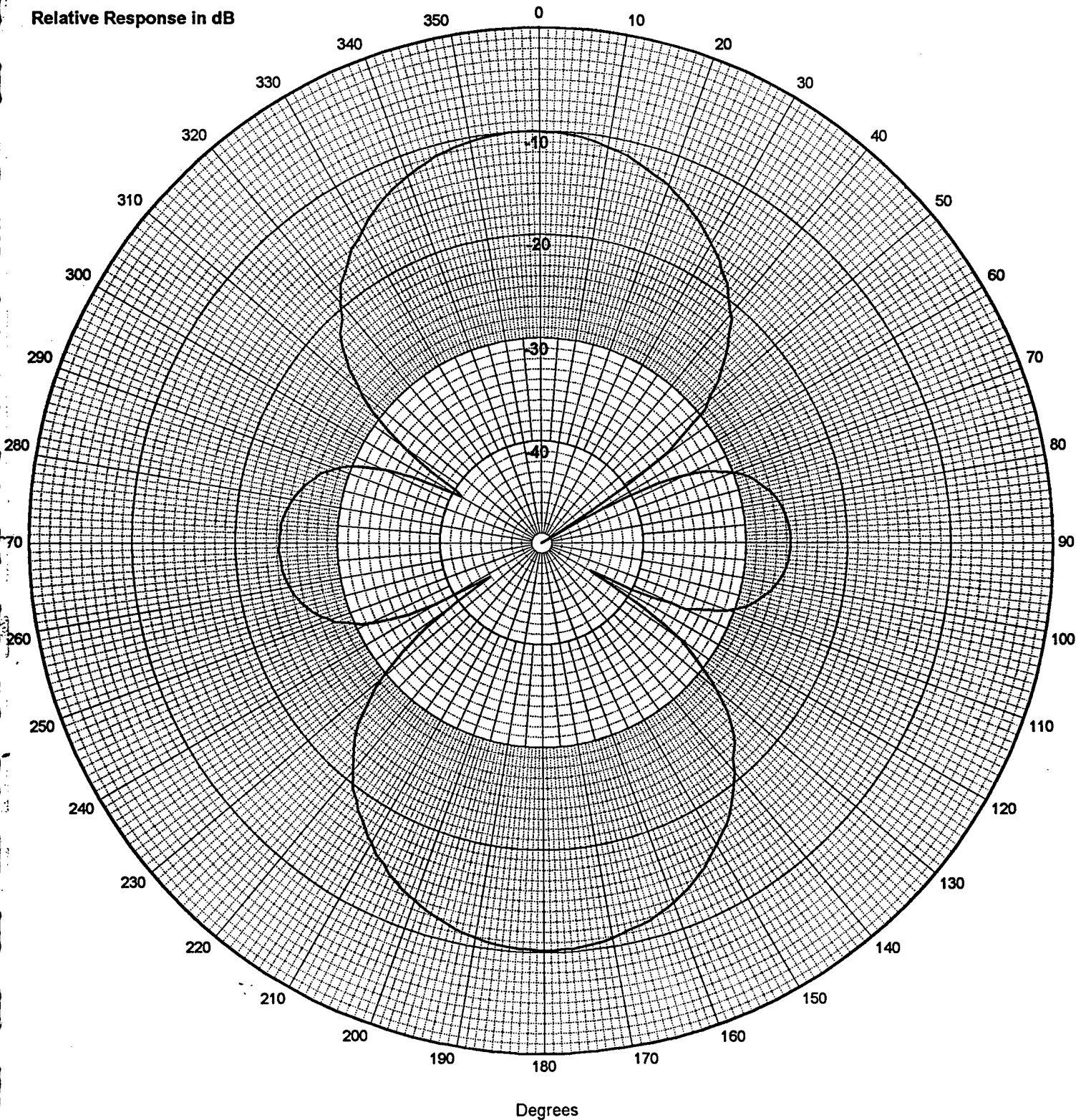
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

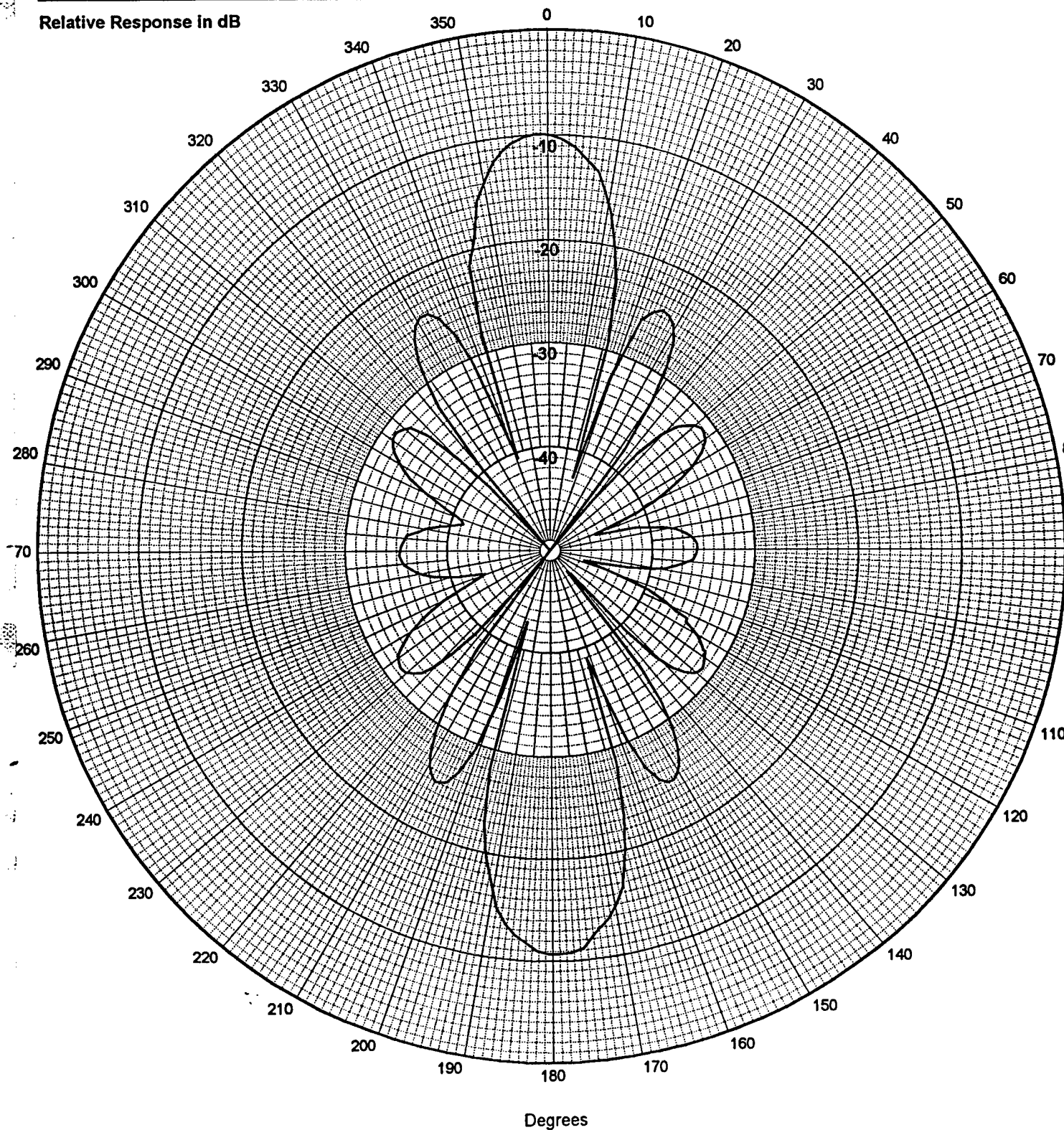
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

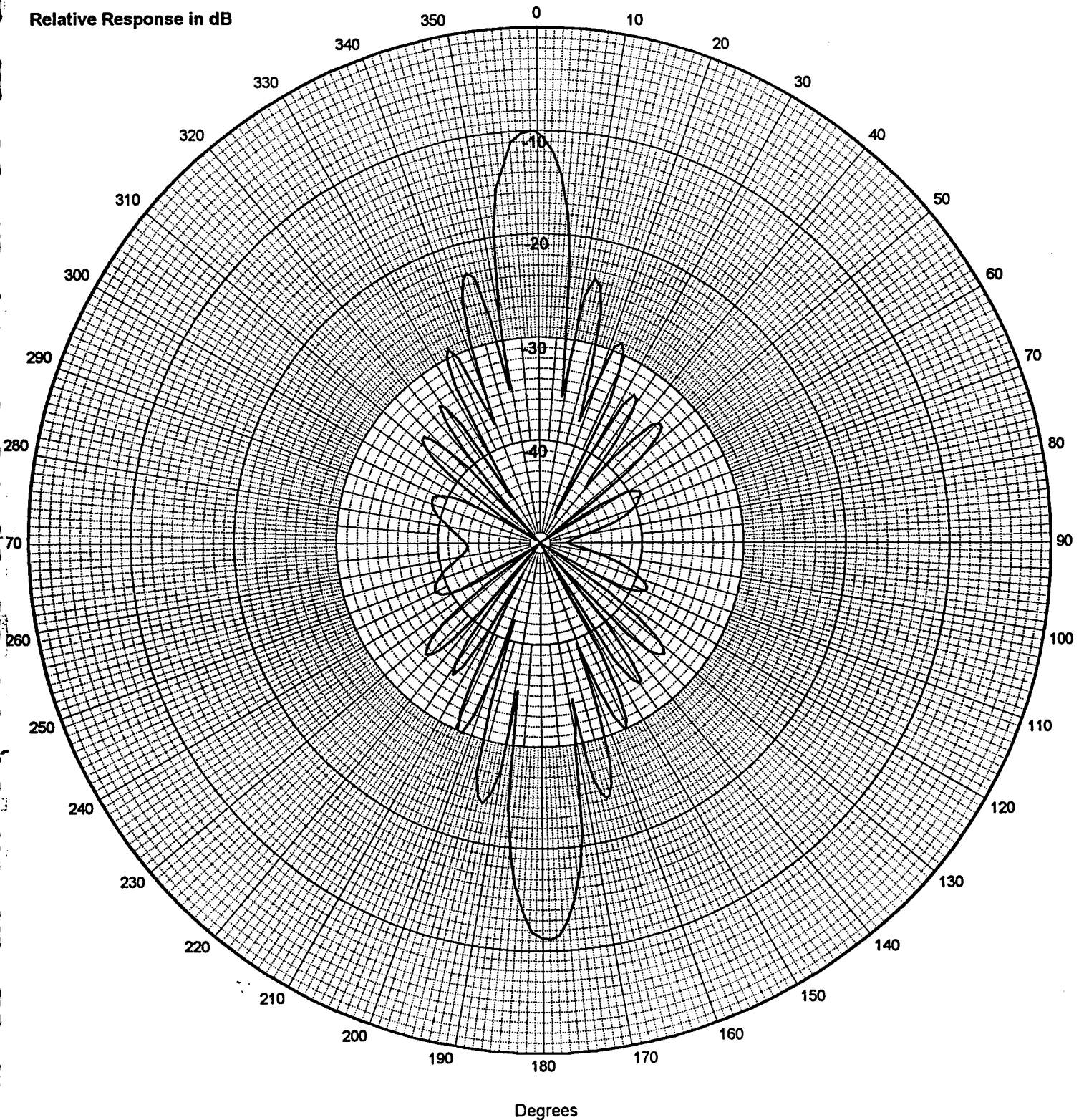
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-67  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB





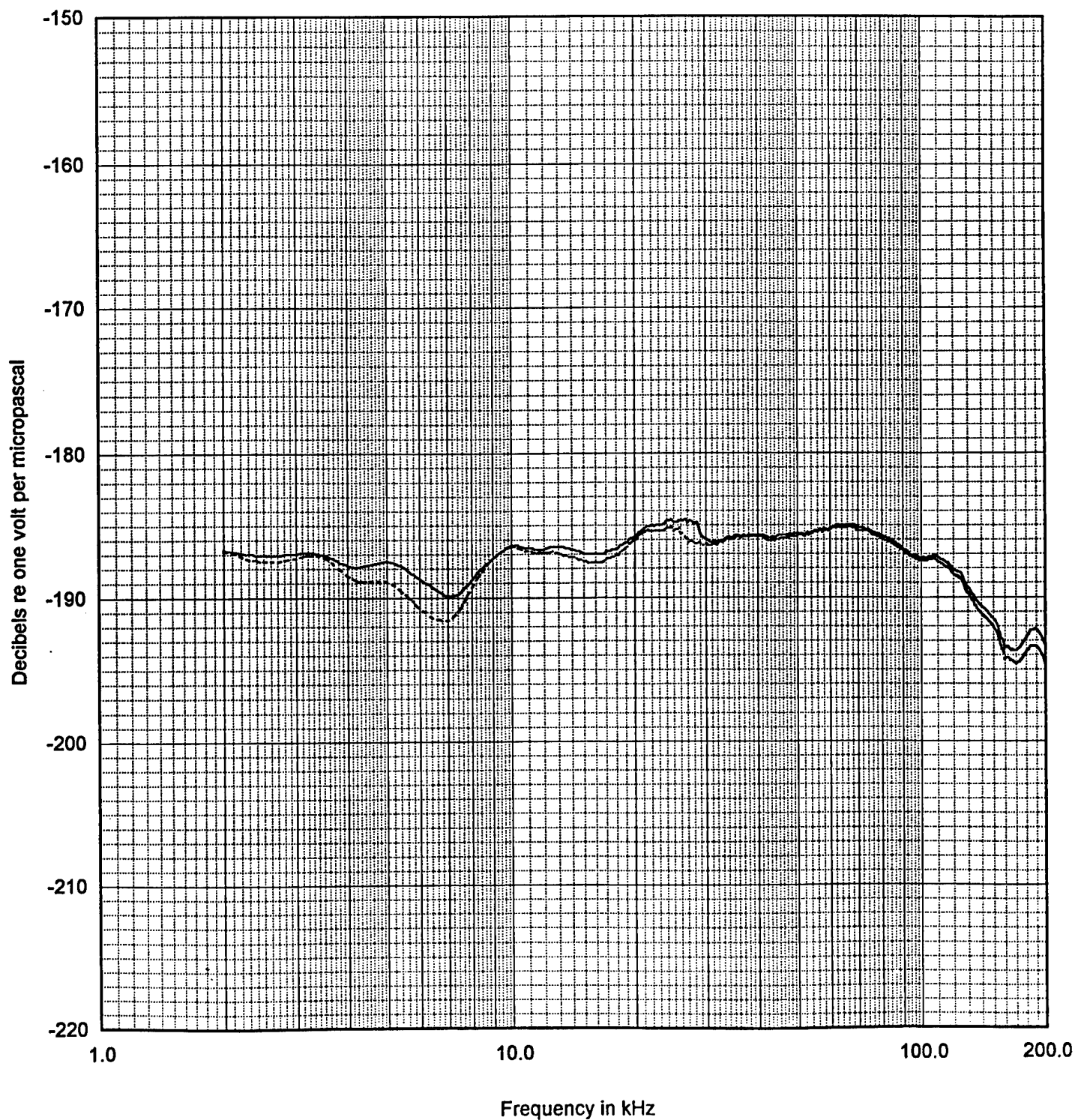
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-70

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m ) Before Pressure  
----- 16 kPa ( 1.6 m ) After Pressure



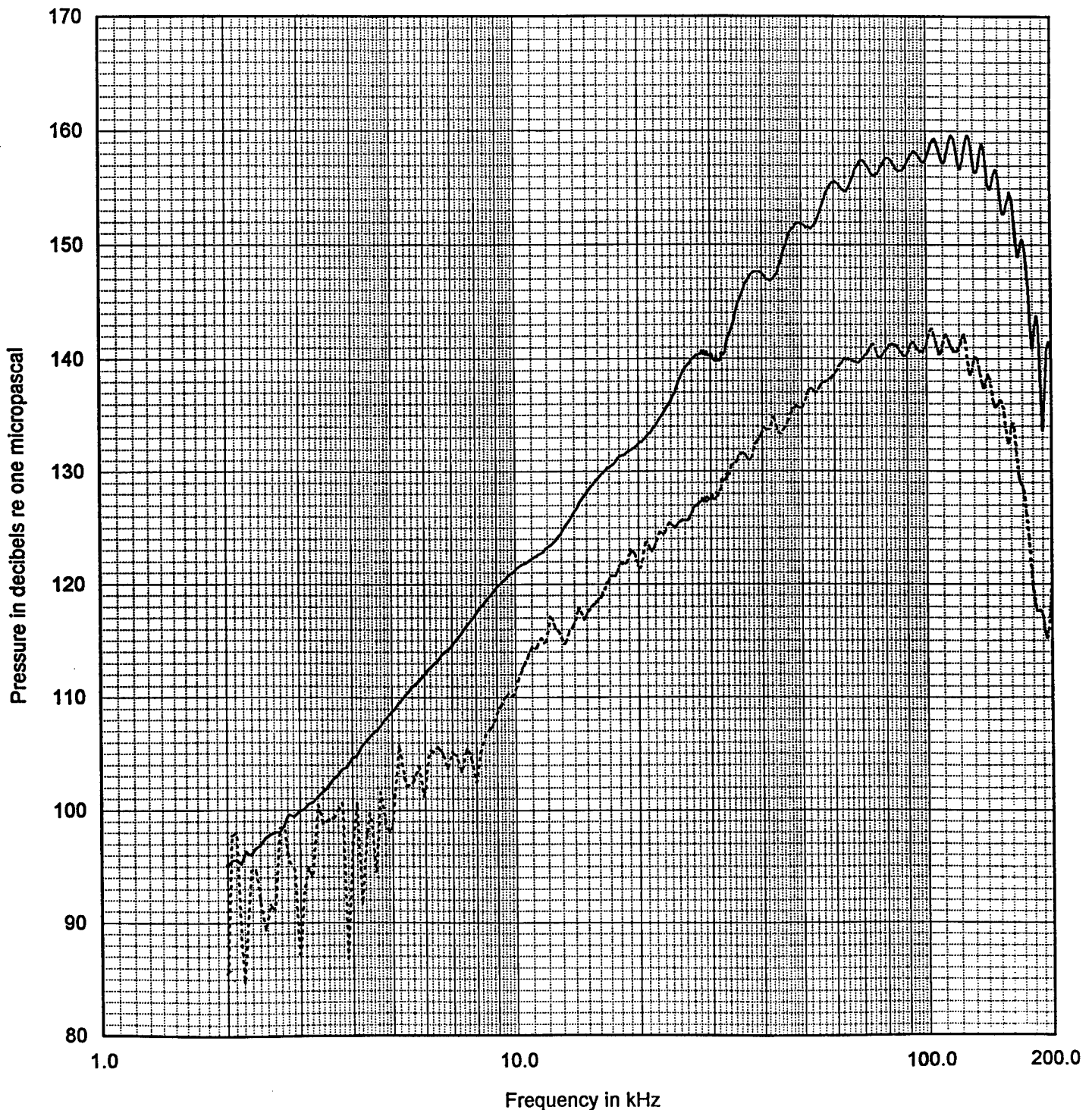
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-70

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m )

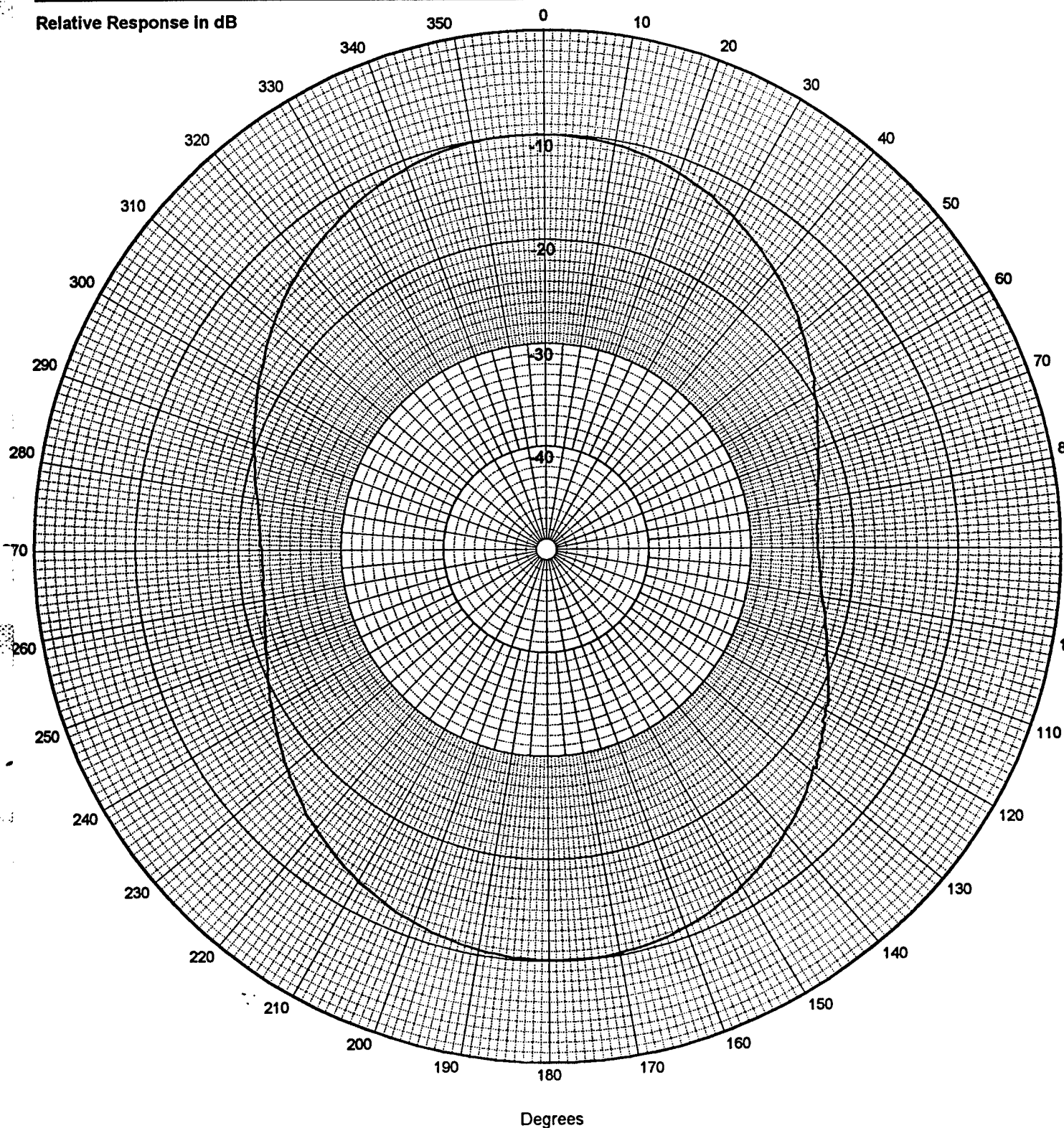
Water Temperature: 4° C

Transmit

XY Plane

10 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m )

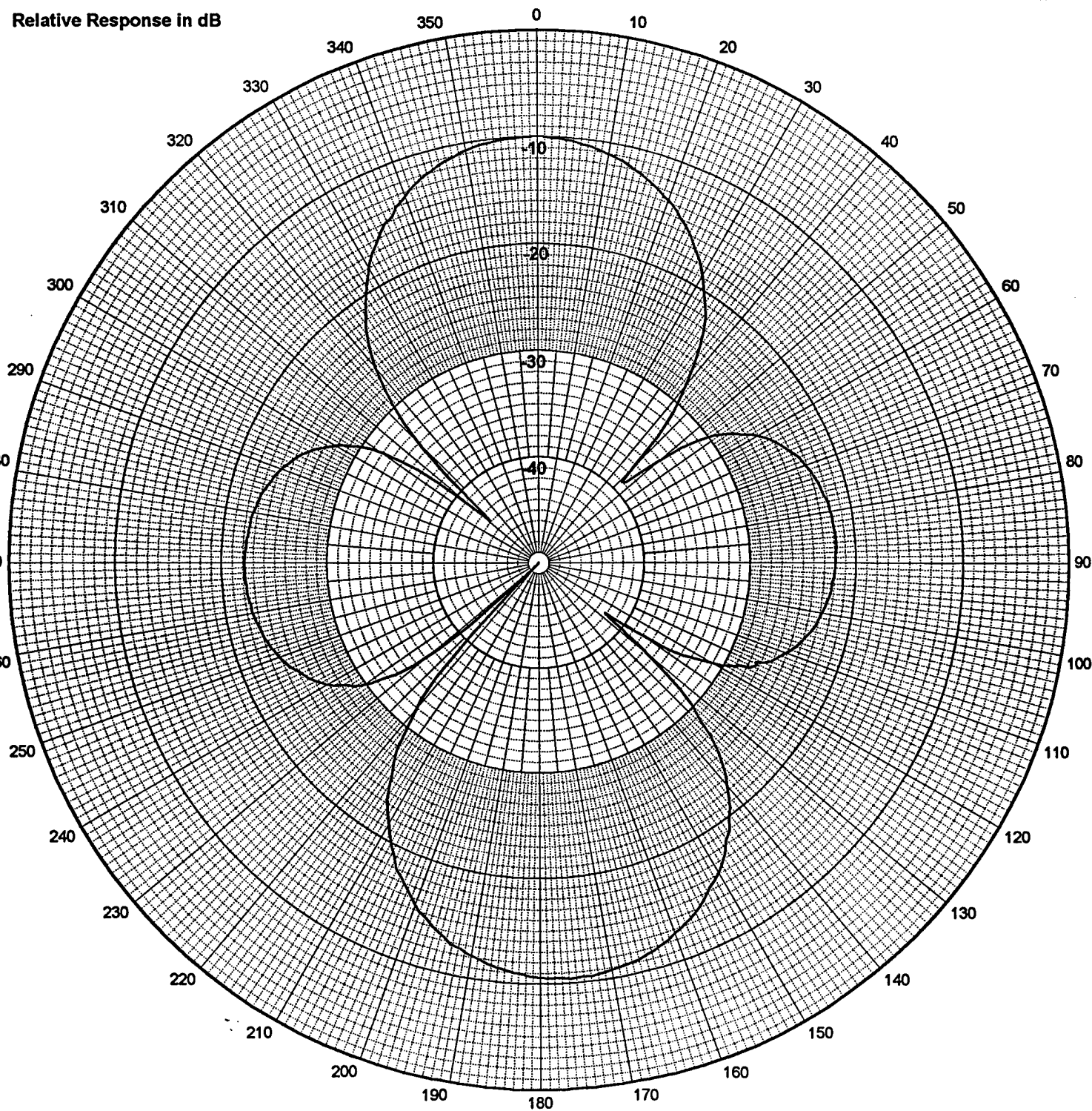
Water Temperature: 4° C

Transmit

XY Plane

20 kHz

Relative Response in dB



Degrees



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m )

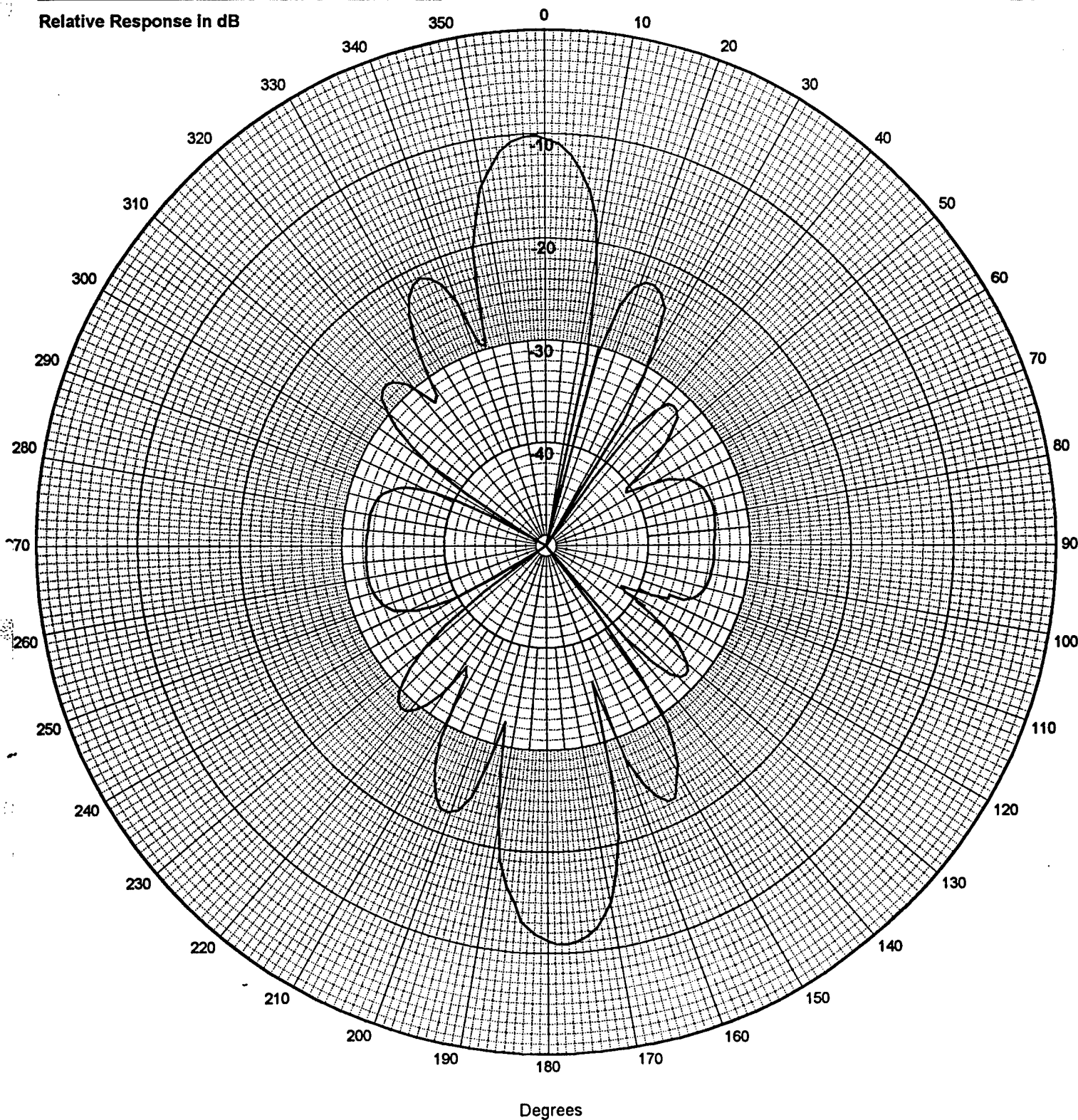
Water Temperature: 4° C

Transmit

XY Plane

50 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m )

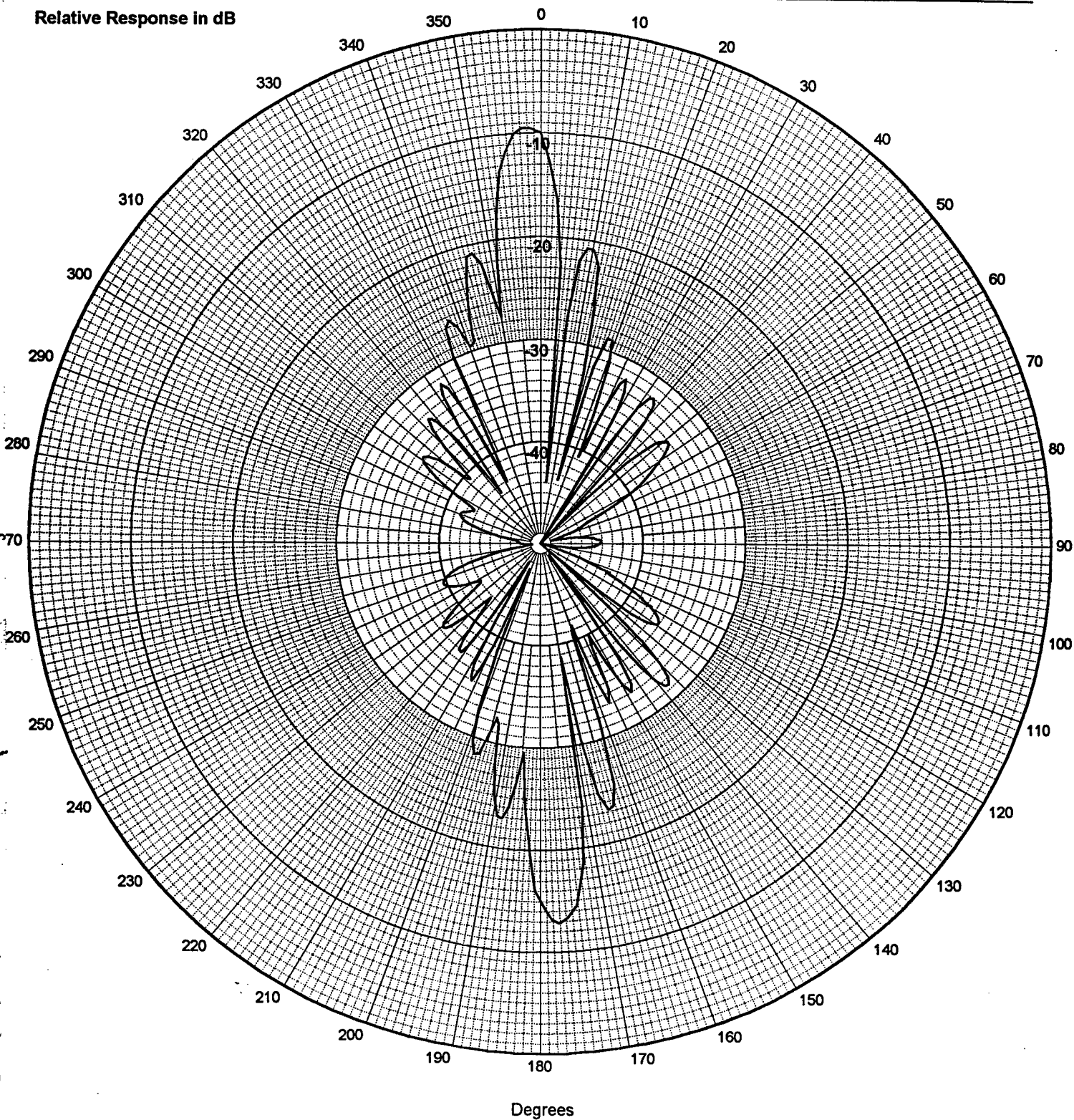
Water Temperature: 4° C

Transmit

XY Plane

100 kHz

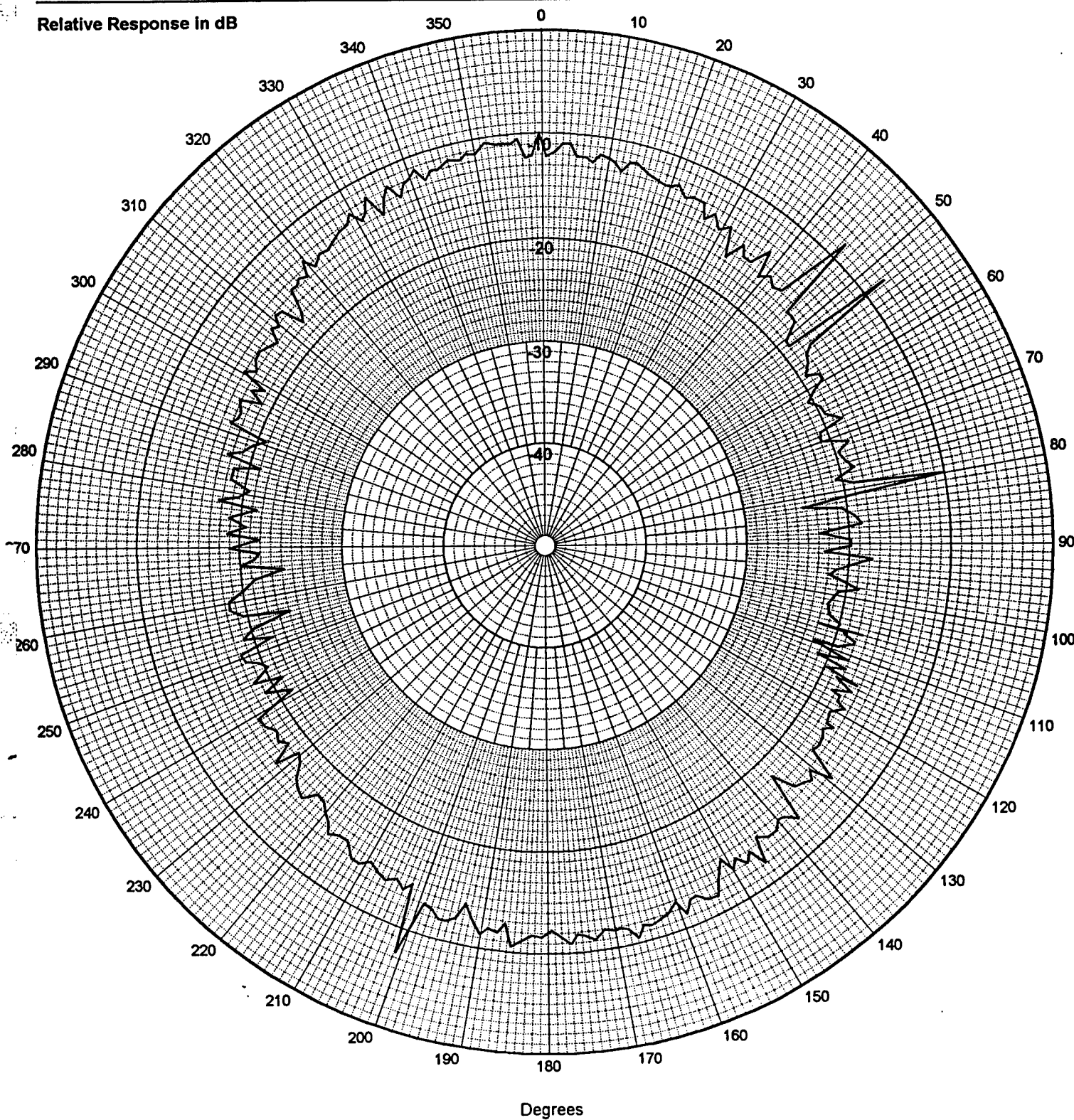
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB



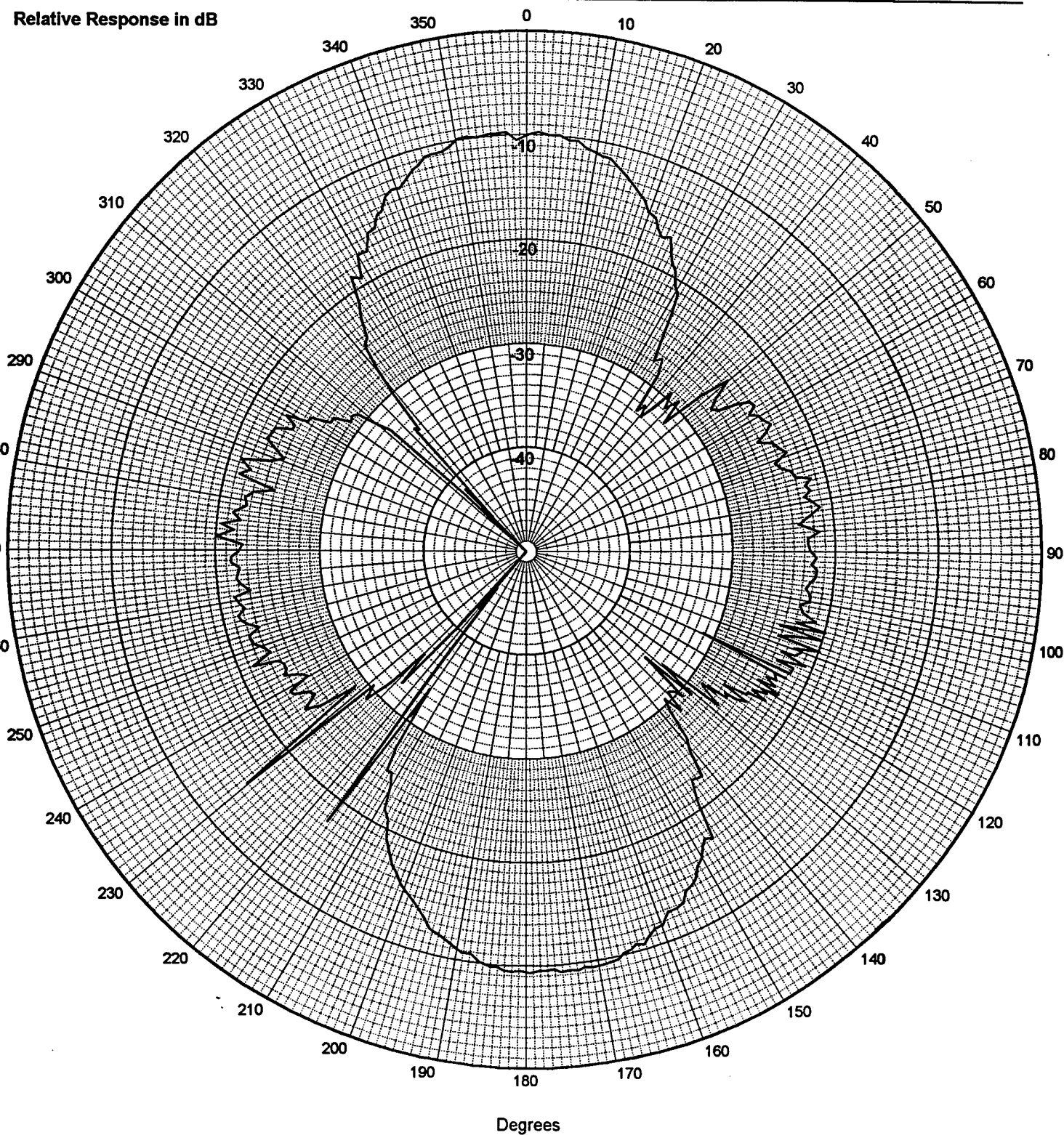
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USRD NO. 0779-65  
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB

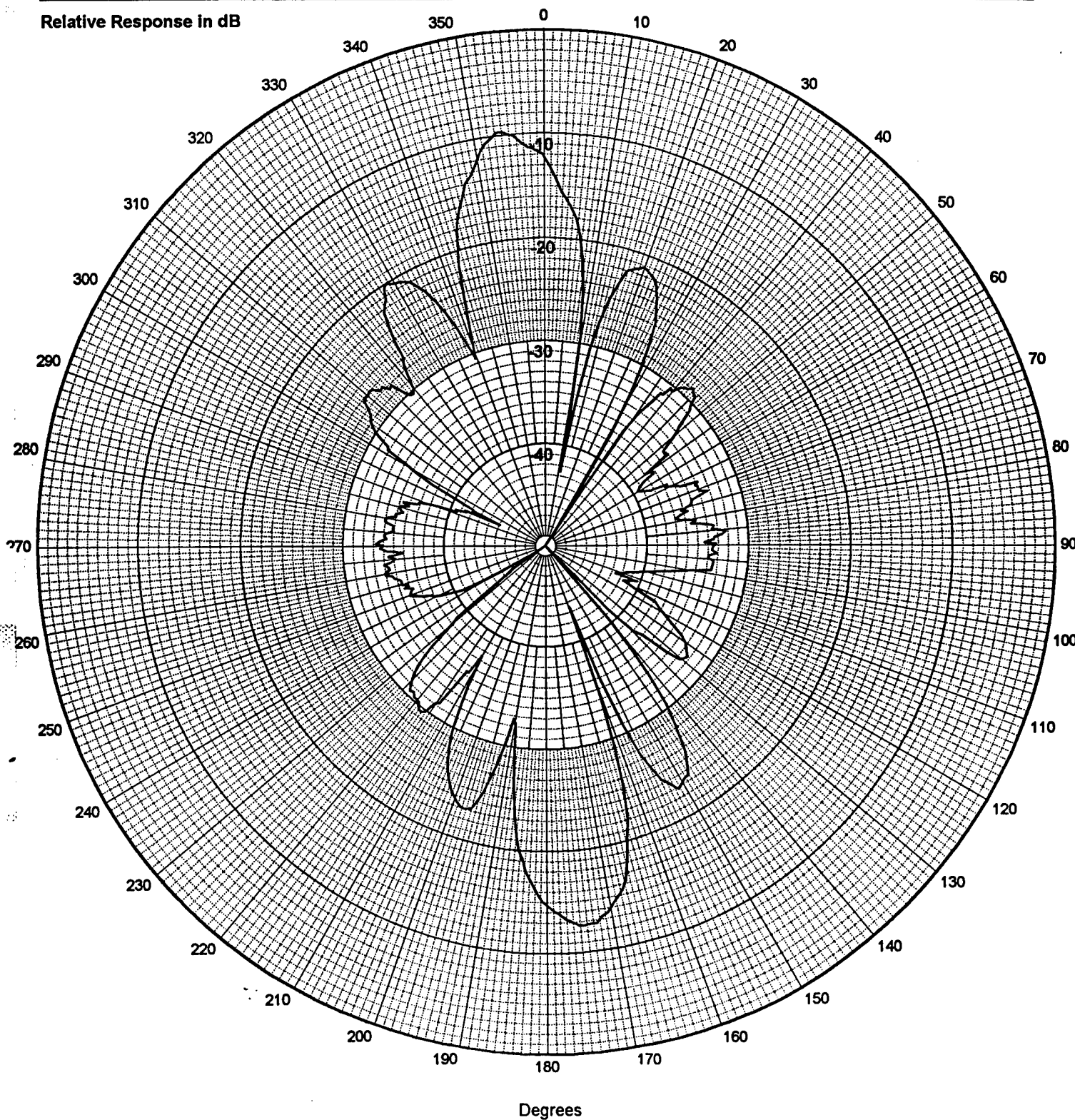




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



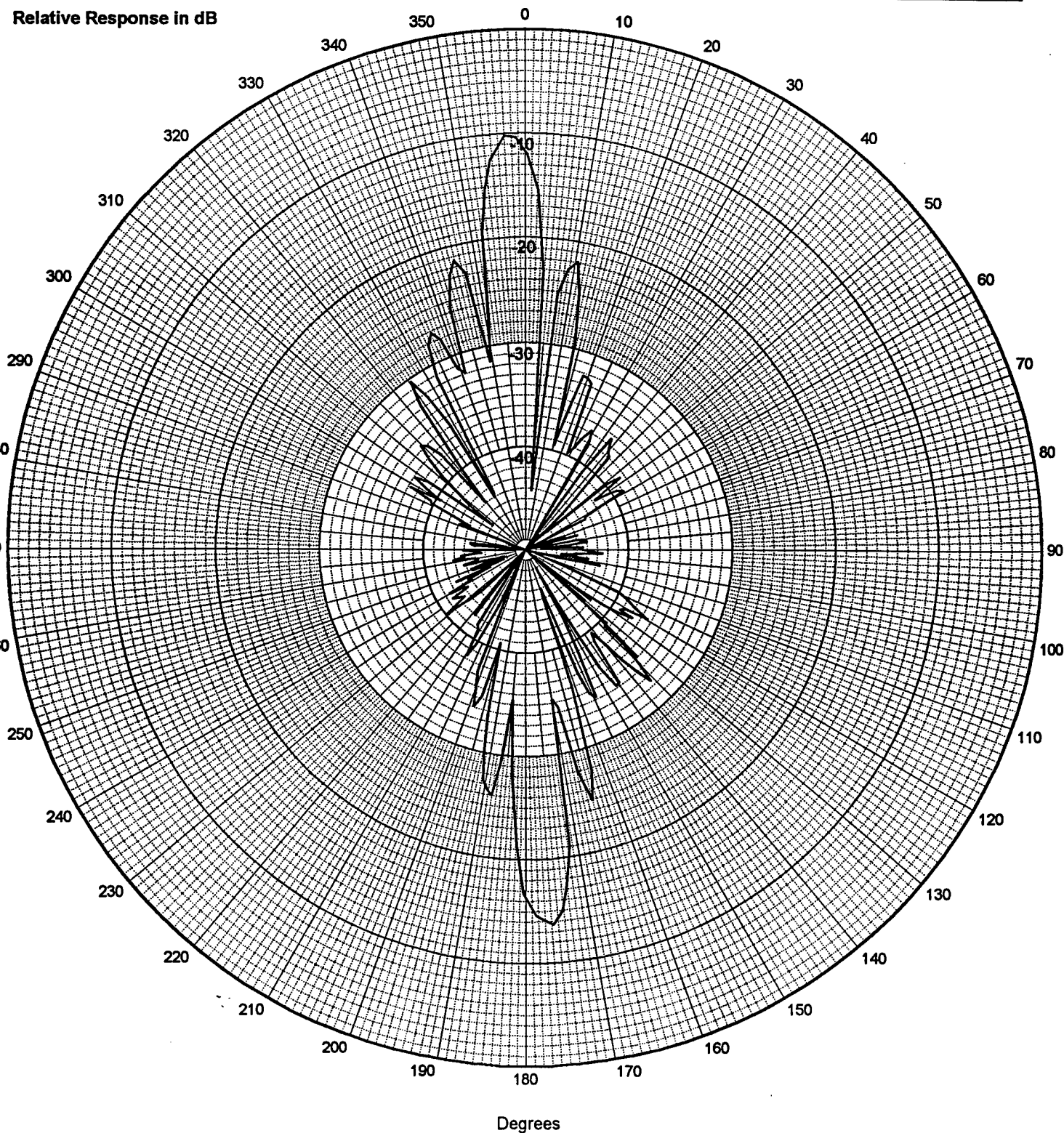
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz

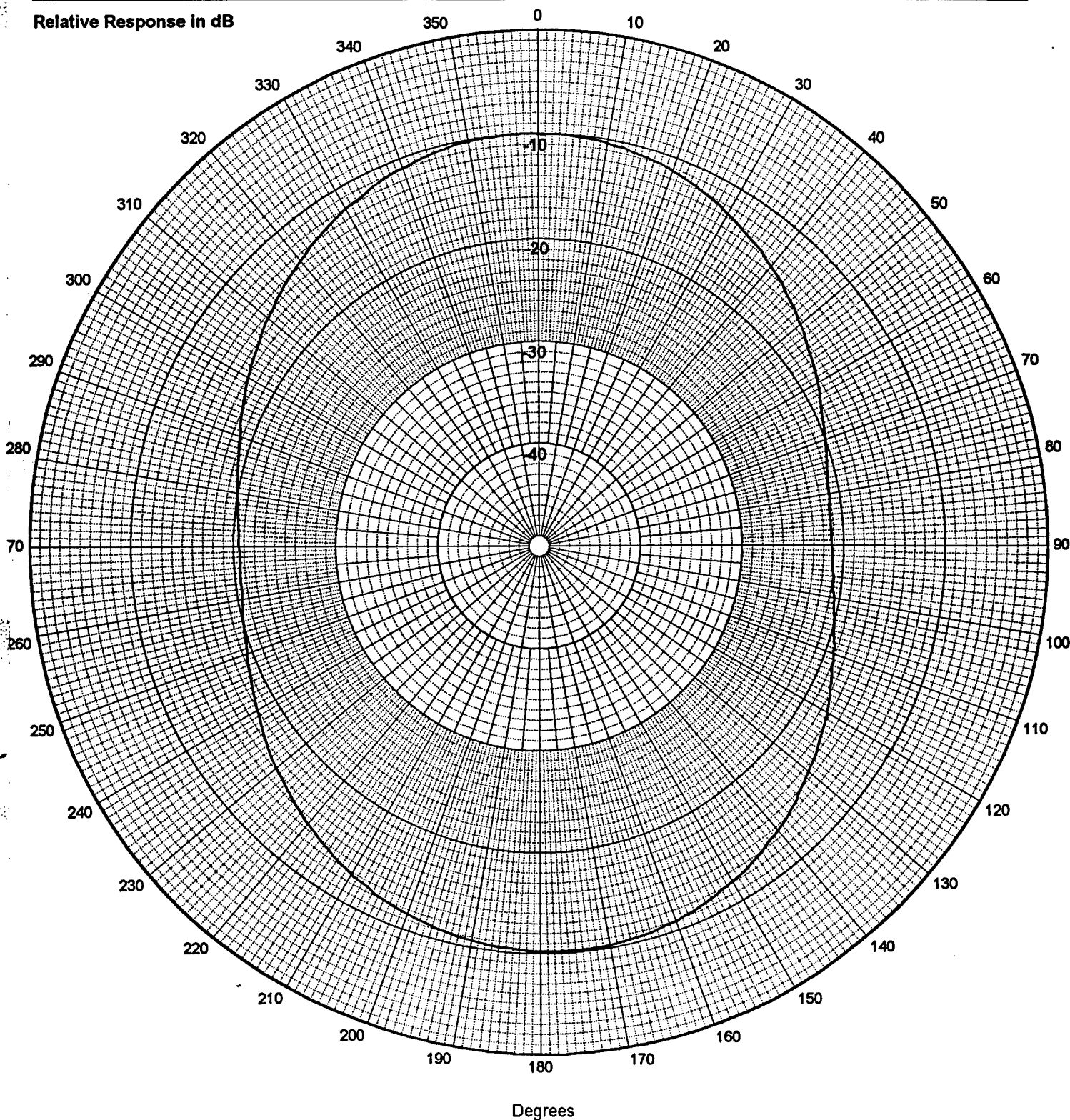
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB



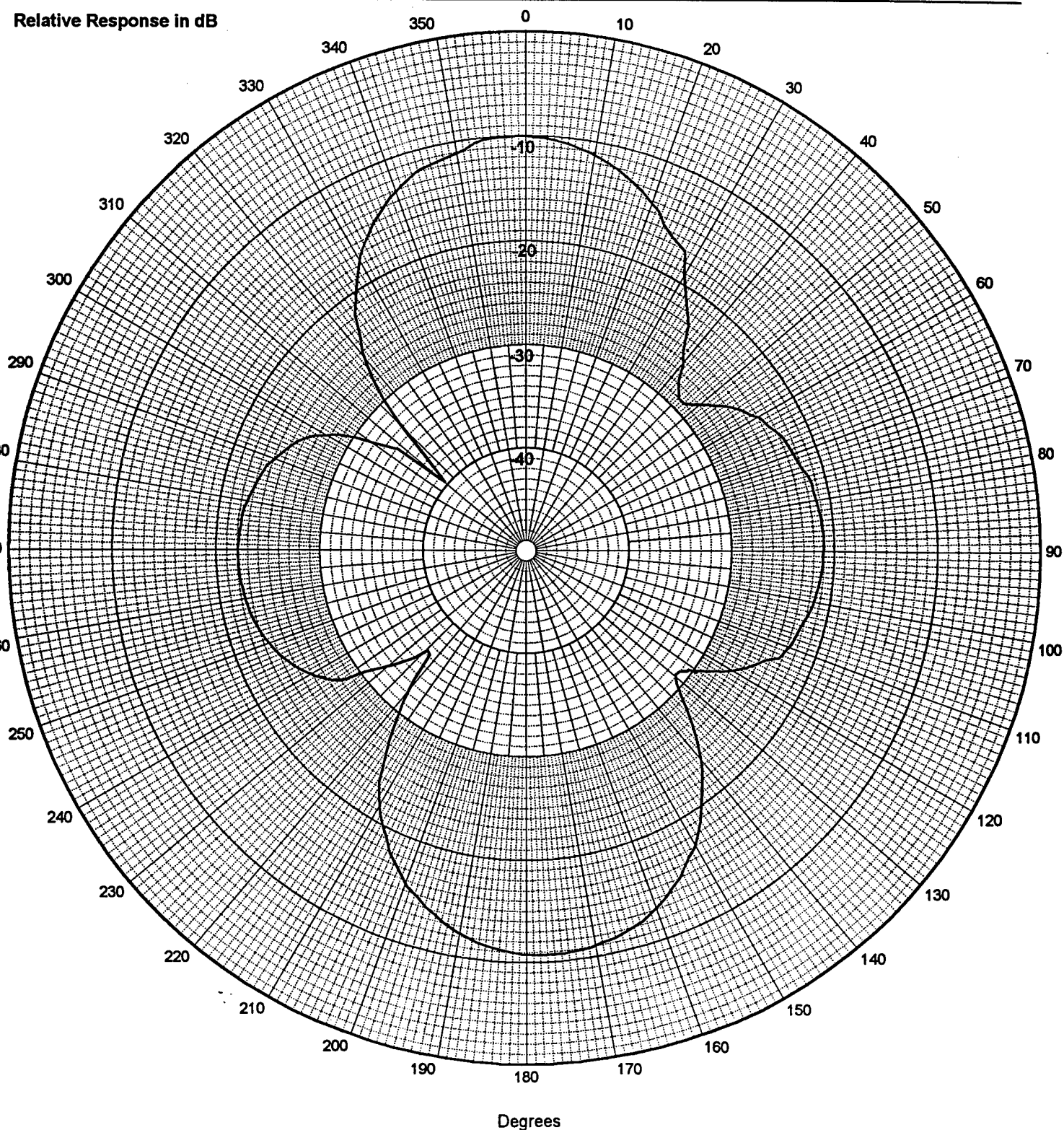
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

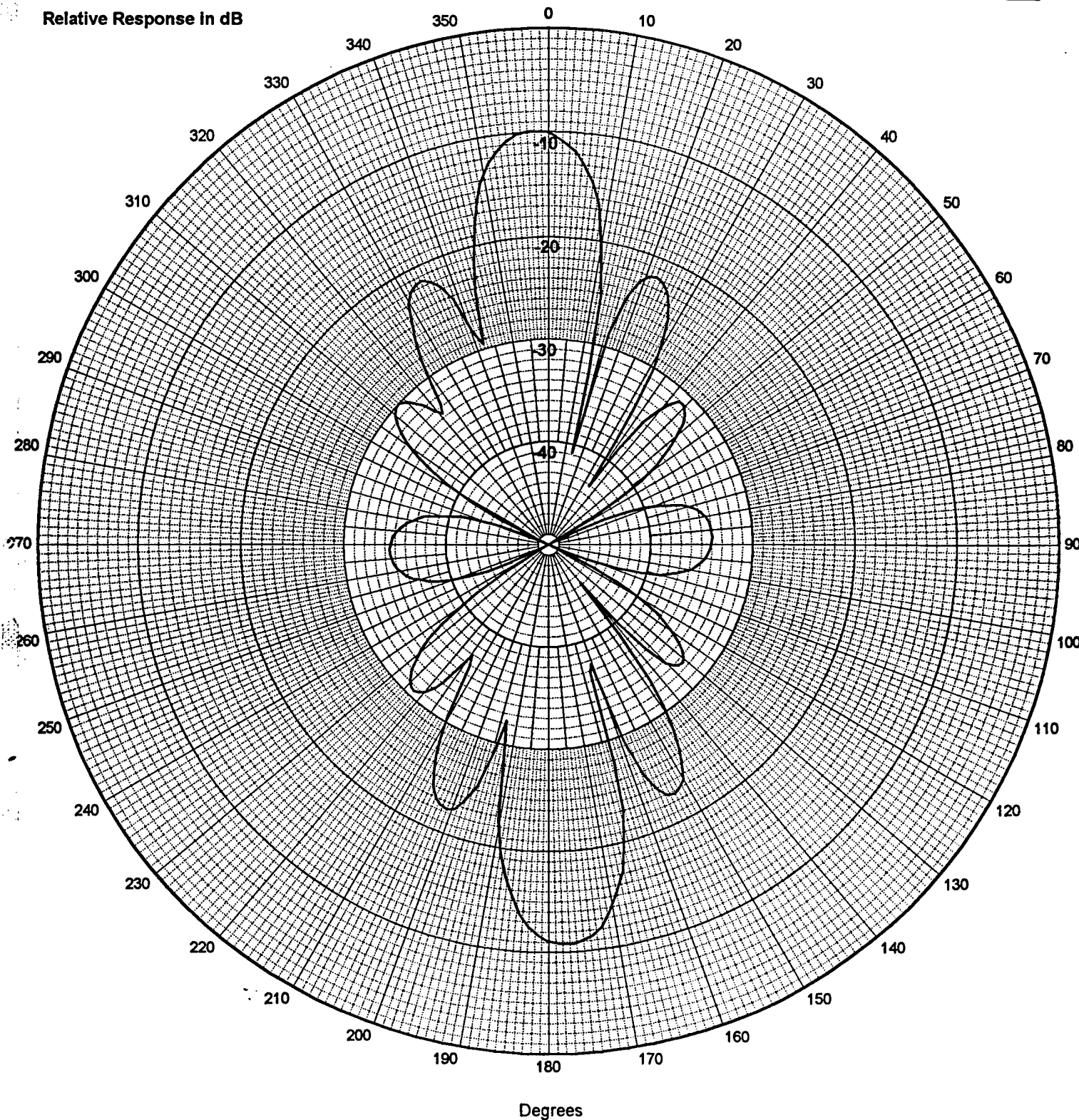
Water Temperature: 4° C

Transmit

XY Plane

50 kHz

Relative Response in dB



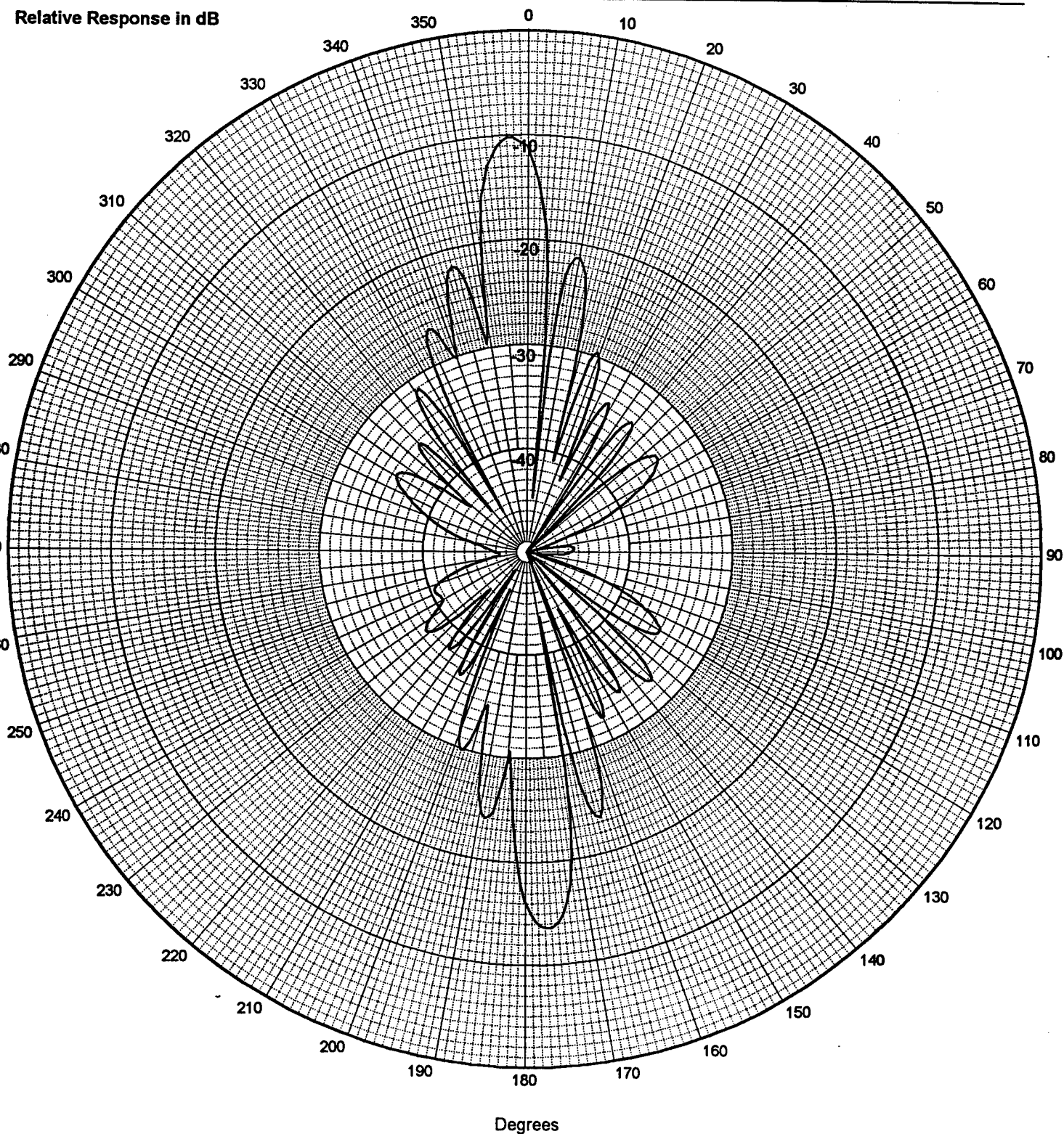
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



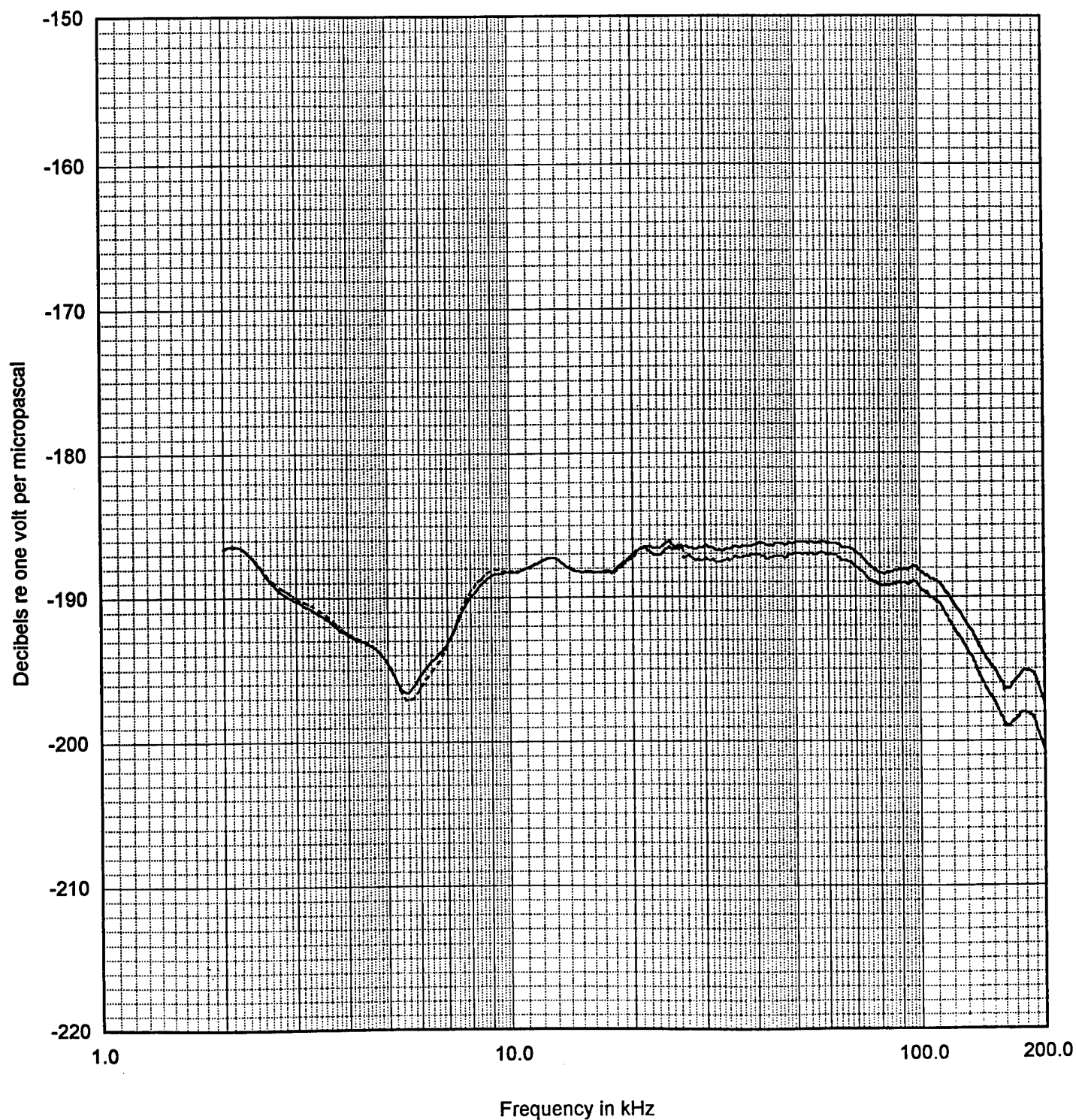
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-70

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m ) Before Pressure  
----- 16 kPa ( 1.6 m ) After Pressure



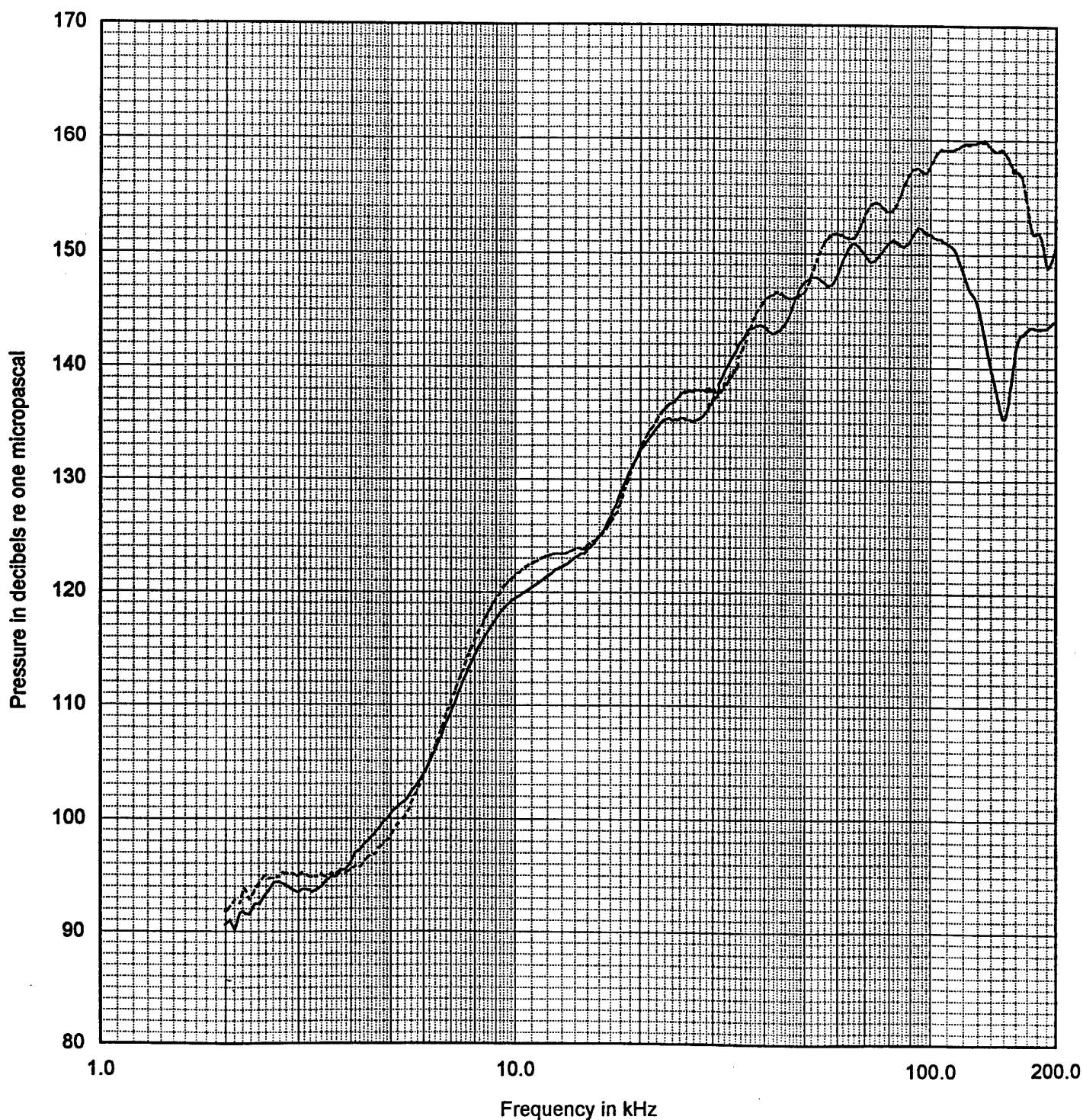
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4-70

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 16 kPa ( 1.6 m) After Pressure





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m )

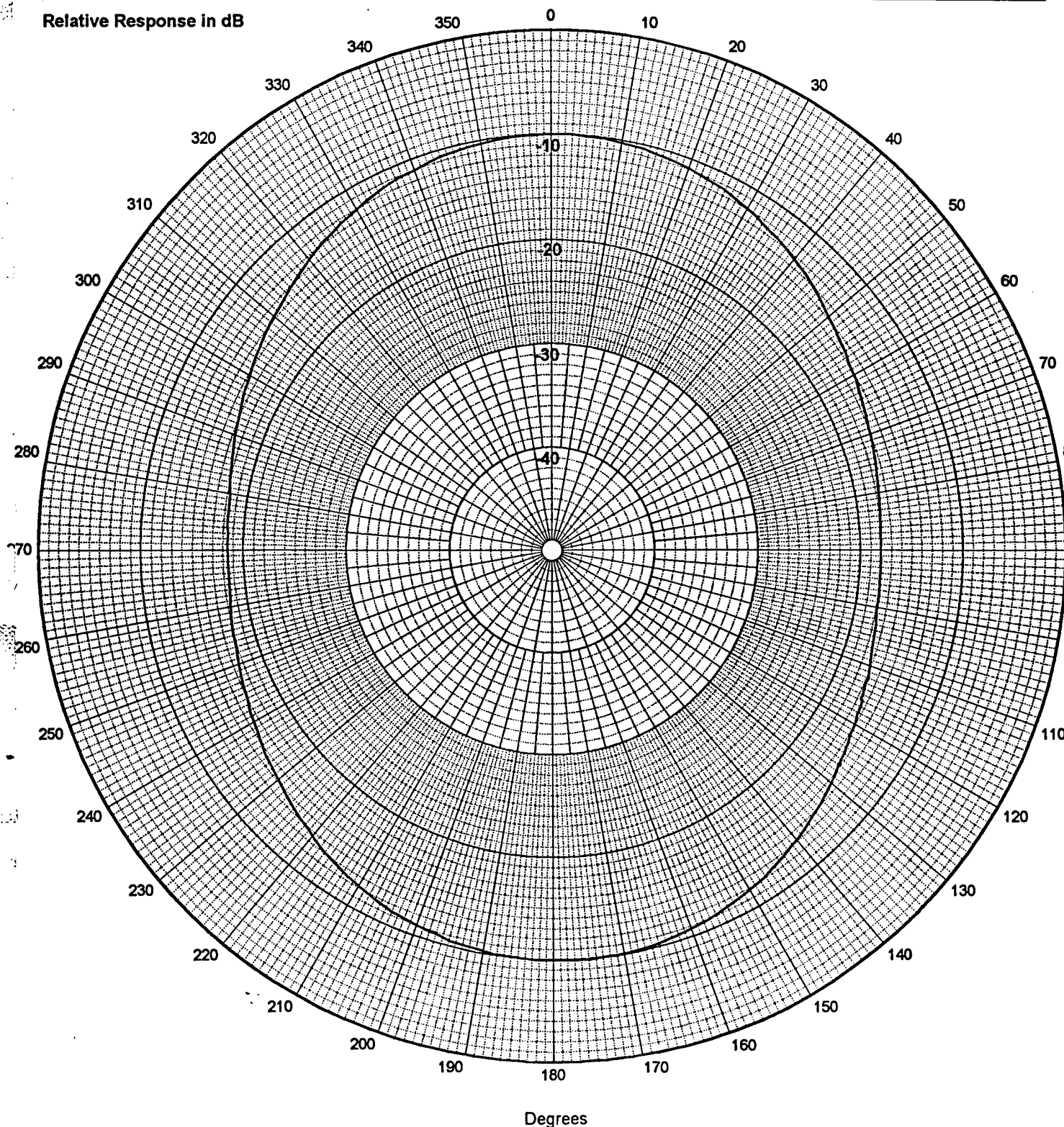
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



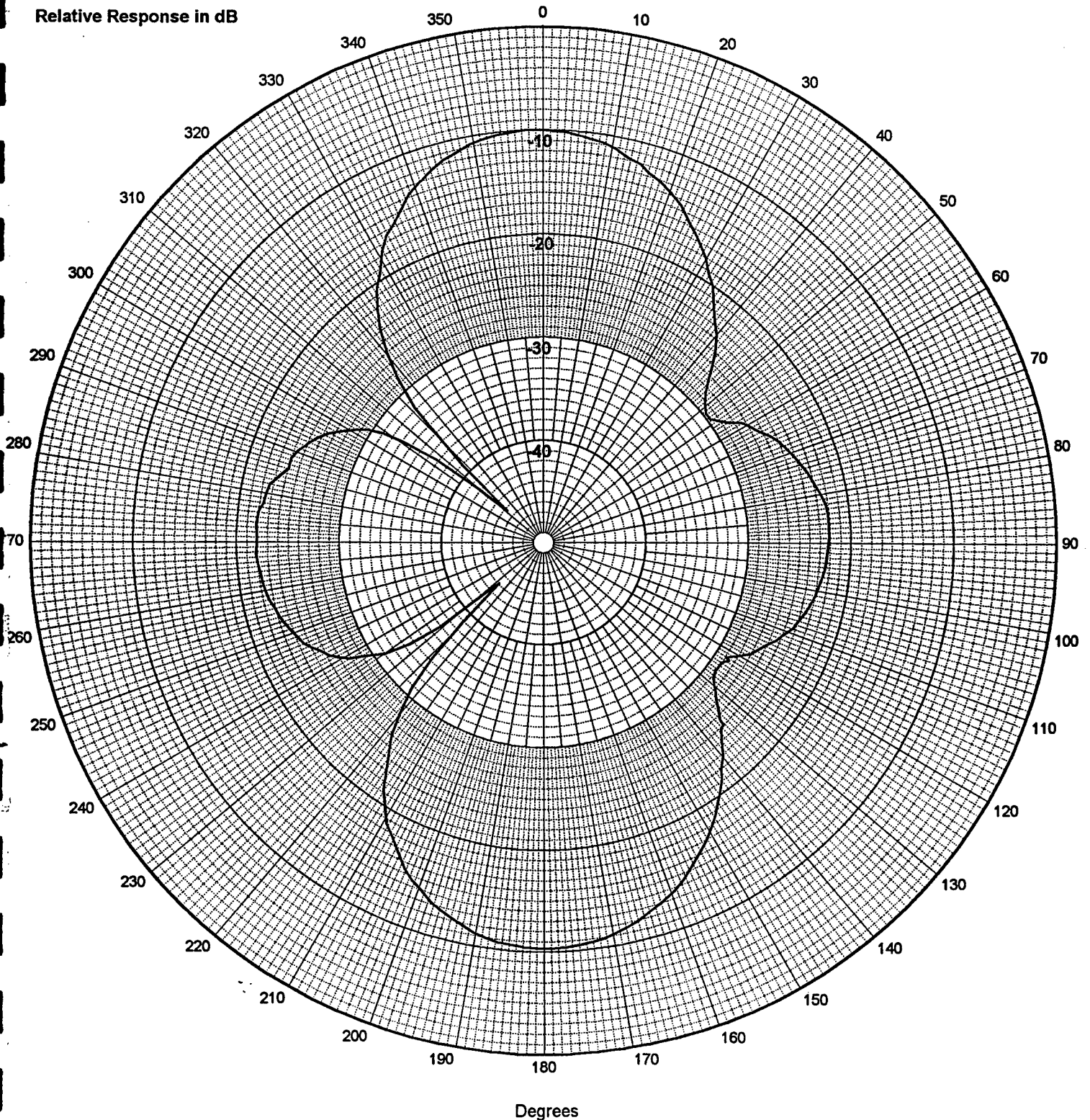
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 16 kPa ( 1.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m )

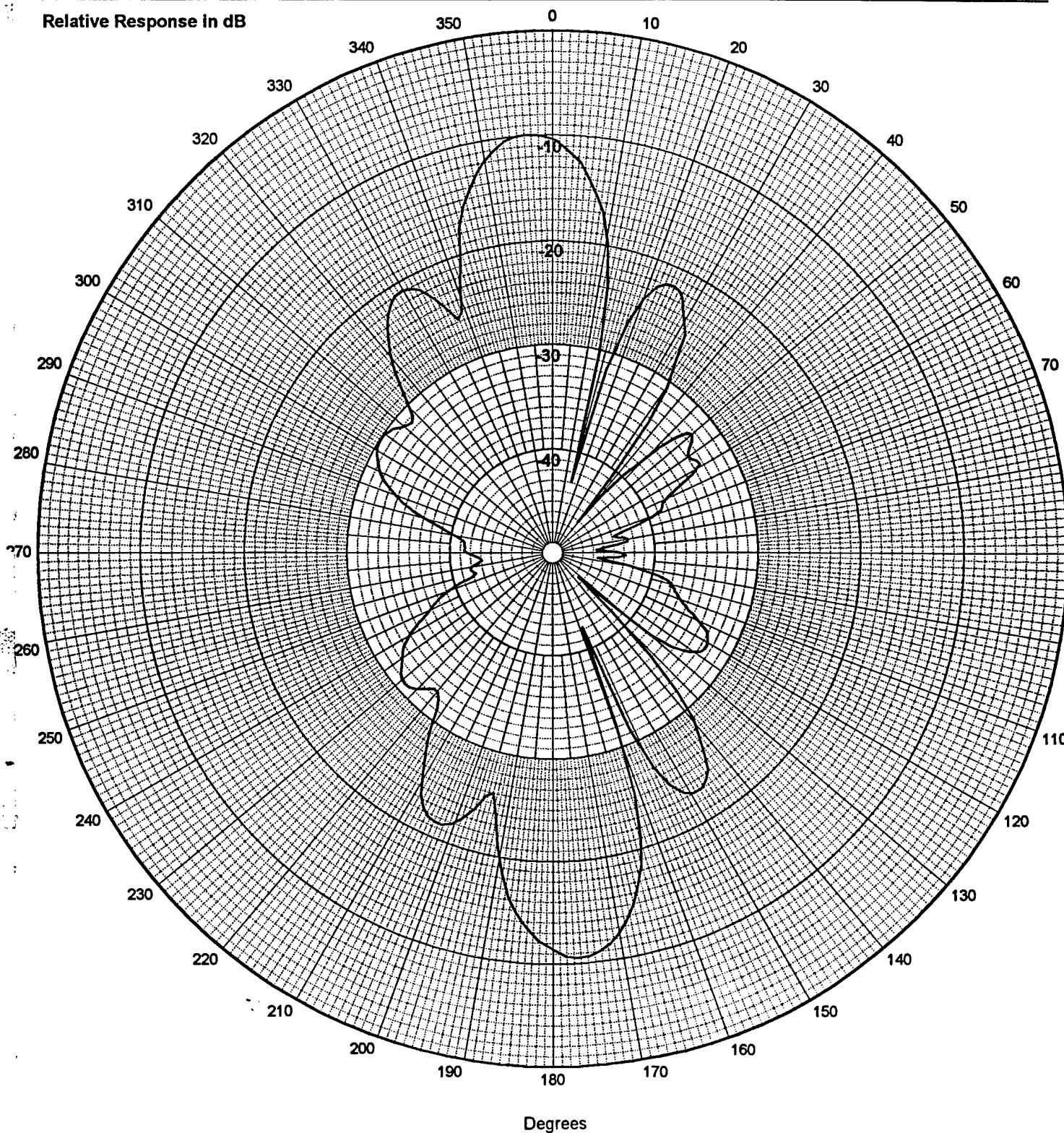
Water Temperature: 22° C

Transmit

XY Plane

50 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m )

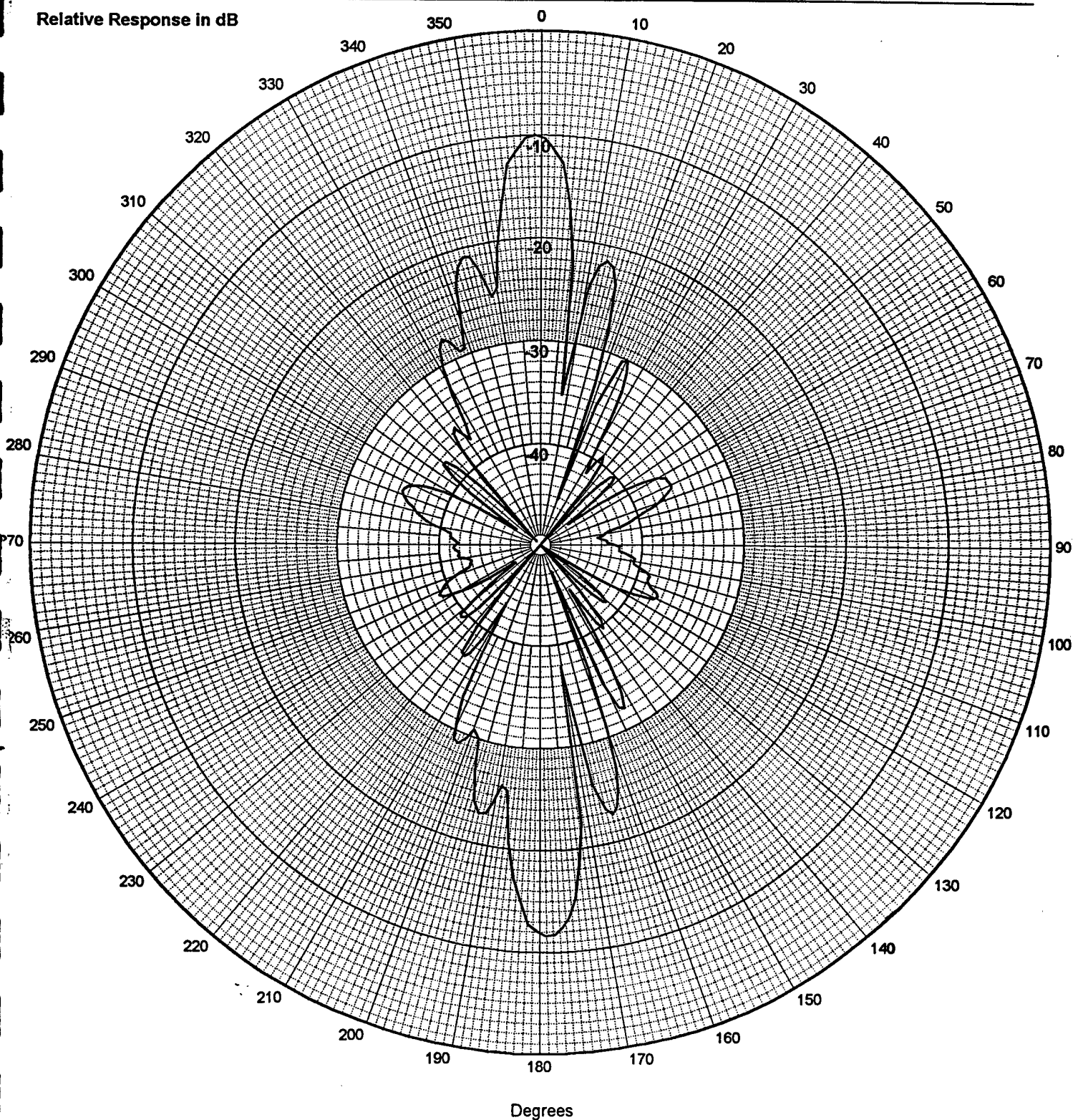
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

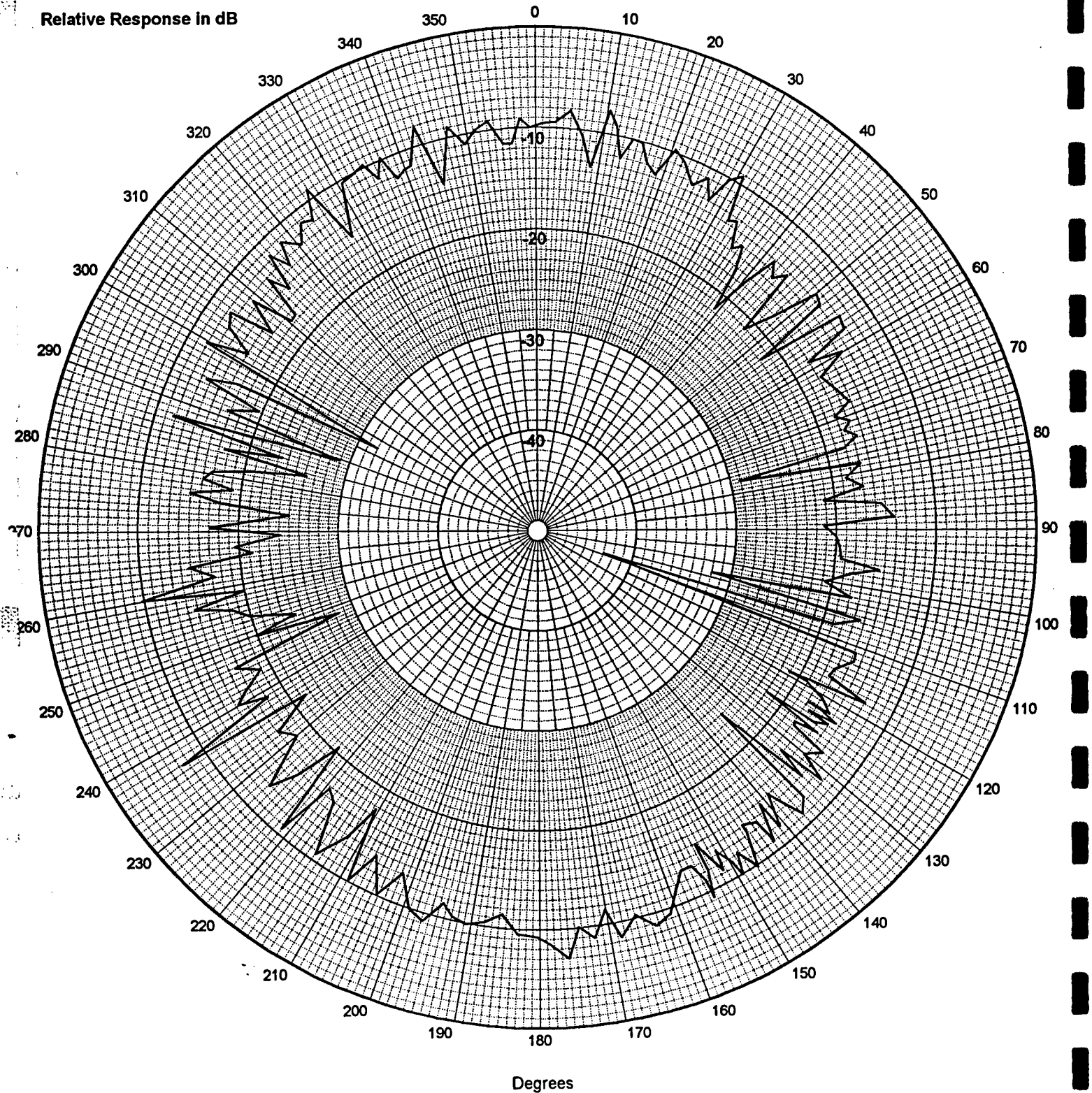
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz



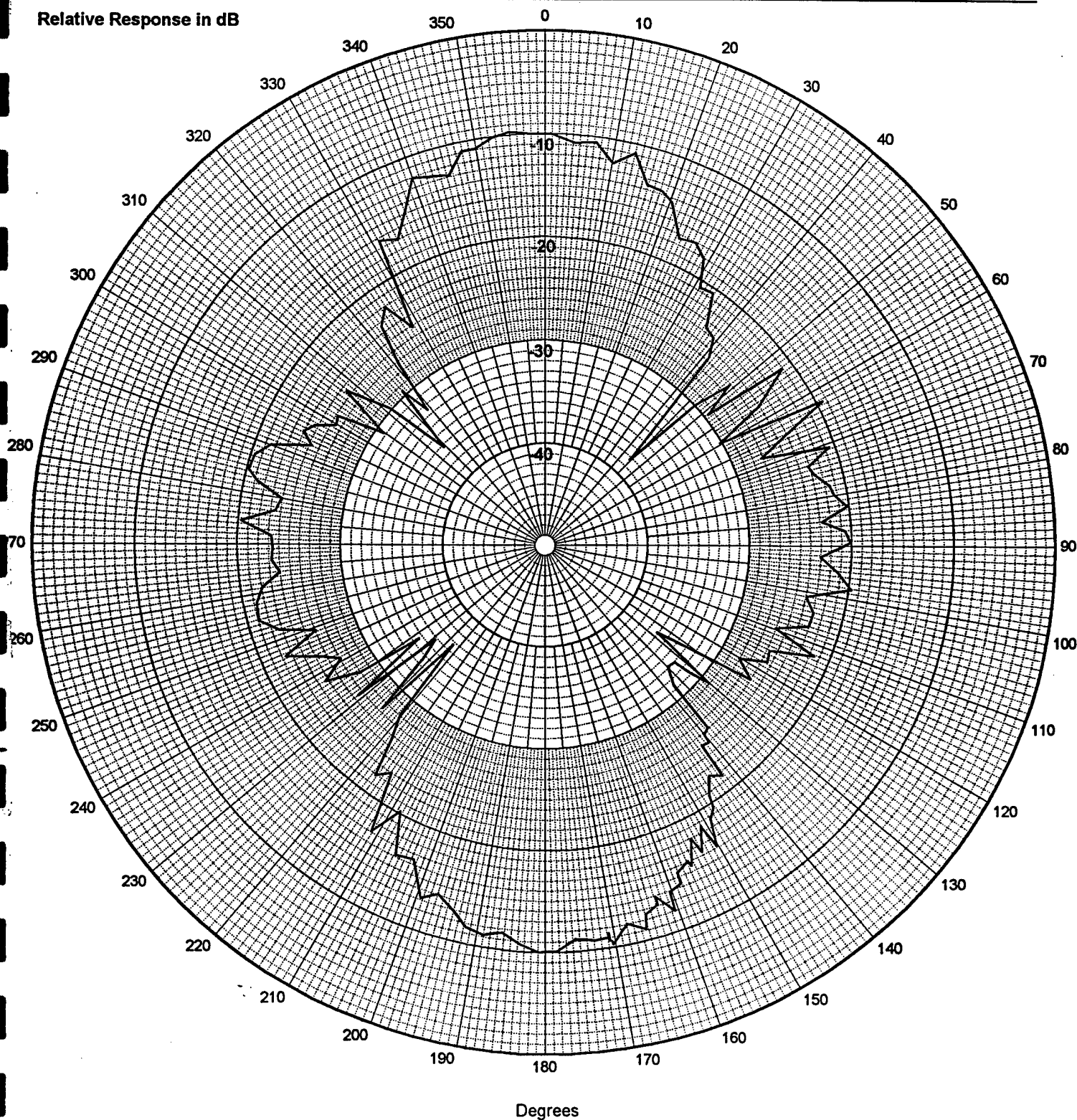
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



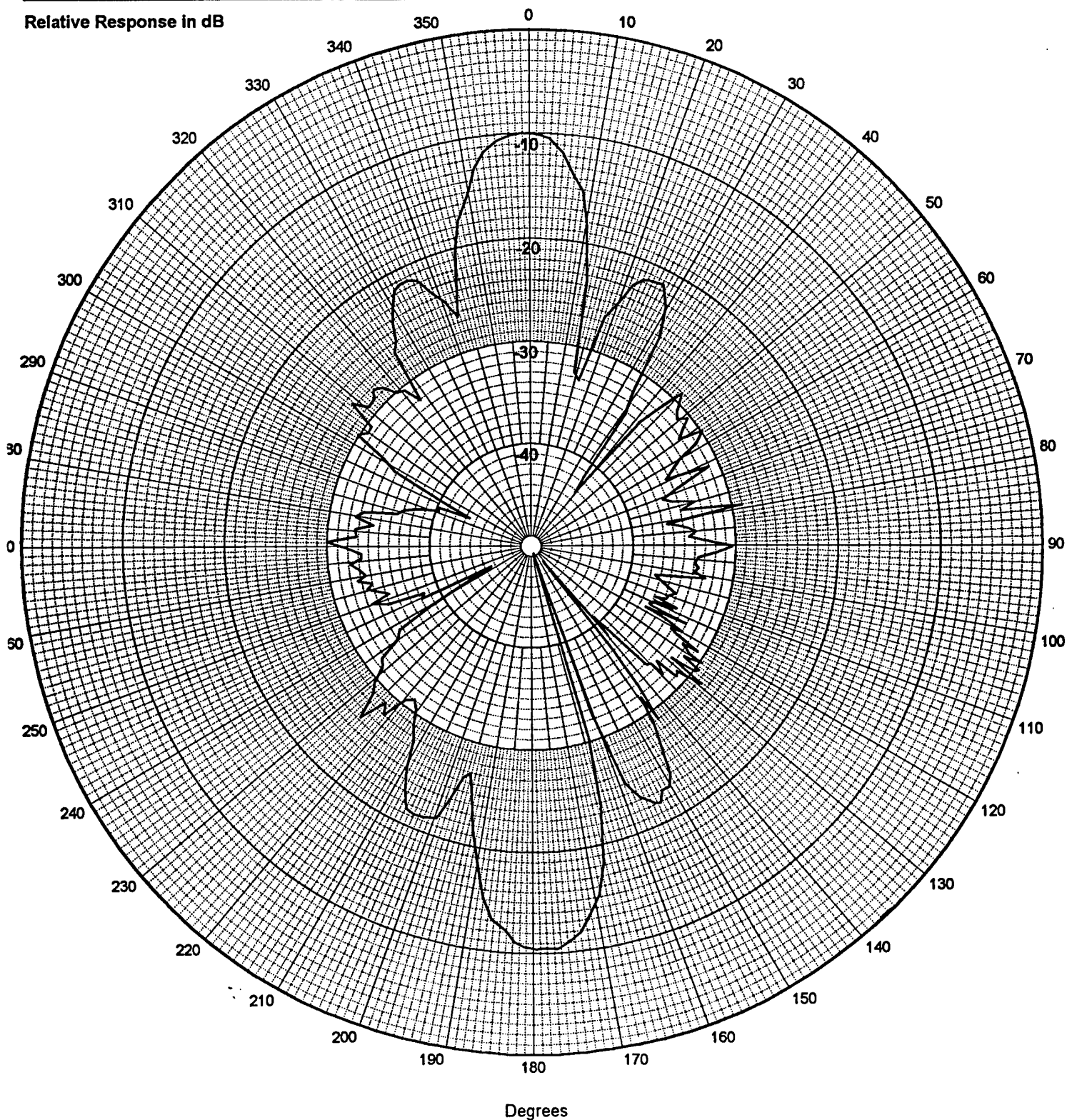
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



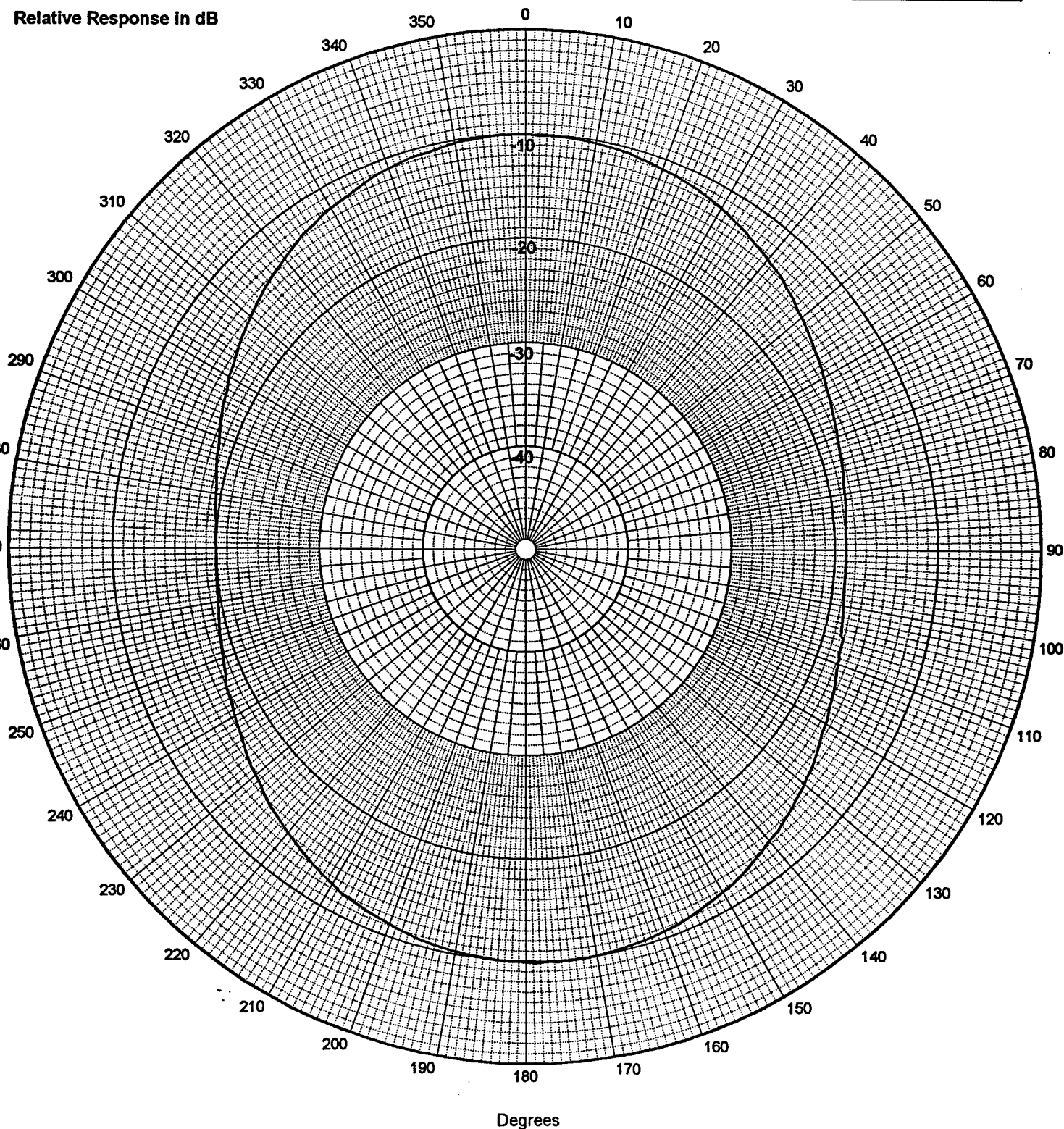
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

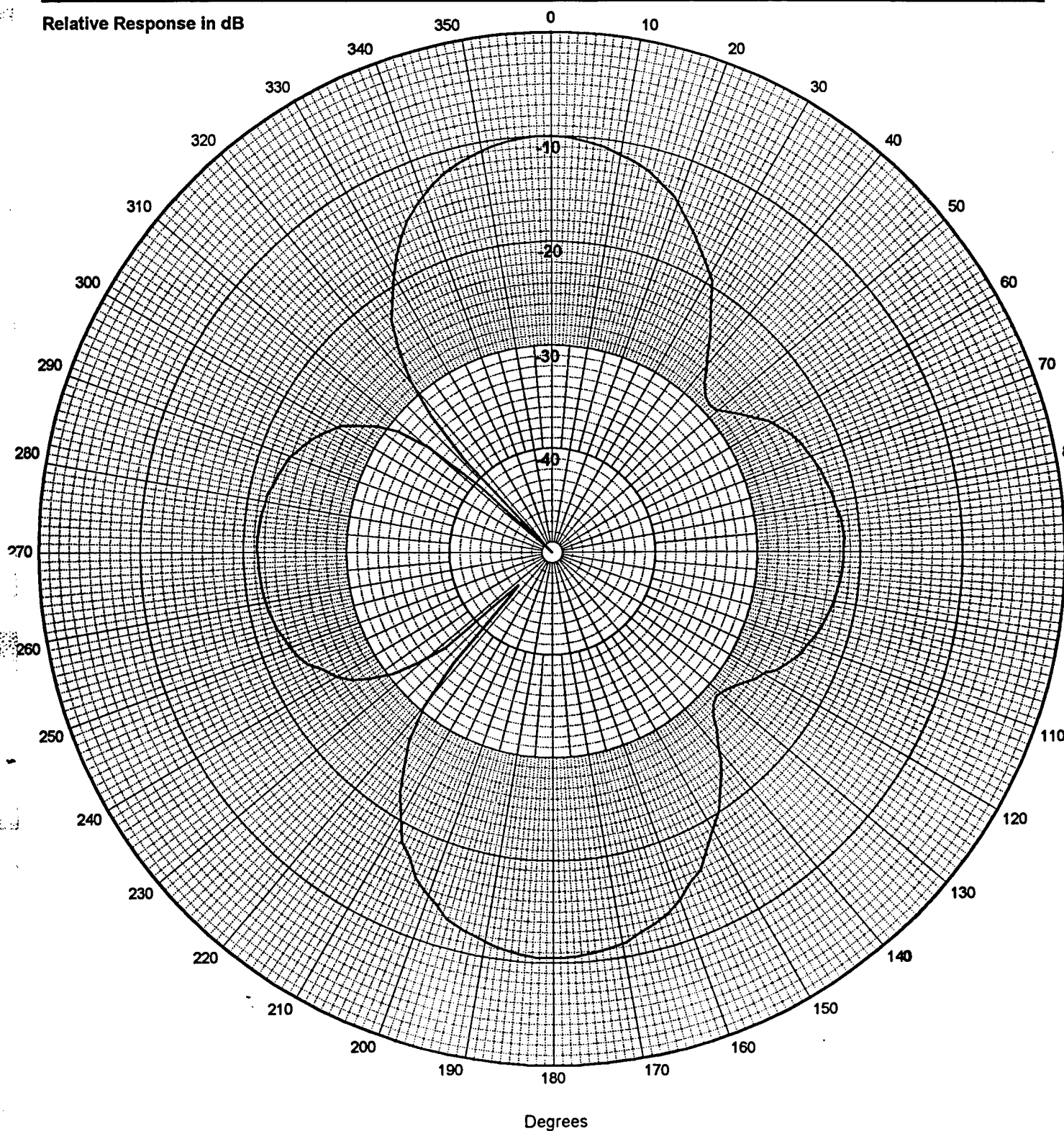
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

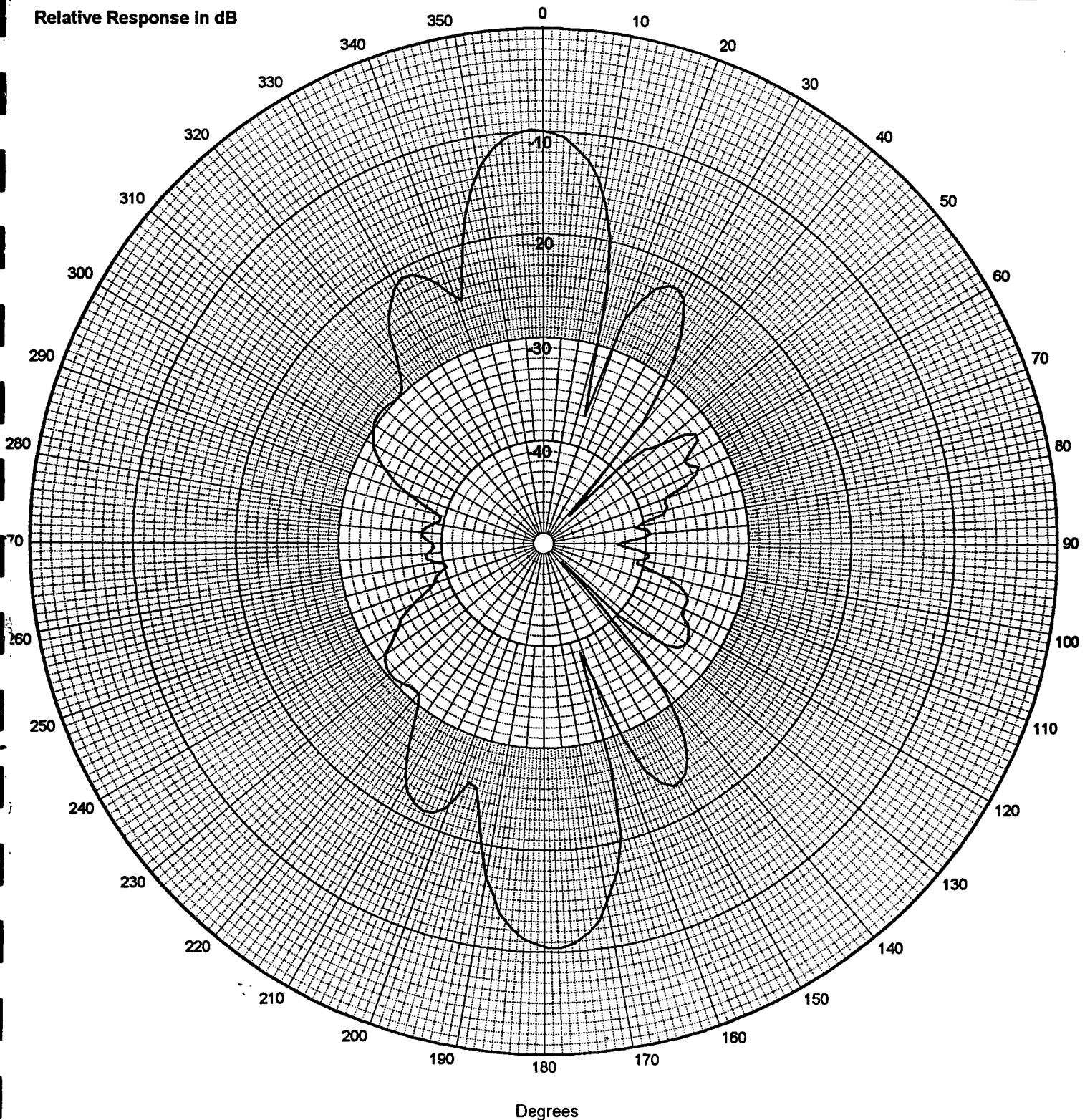
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4-70

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

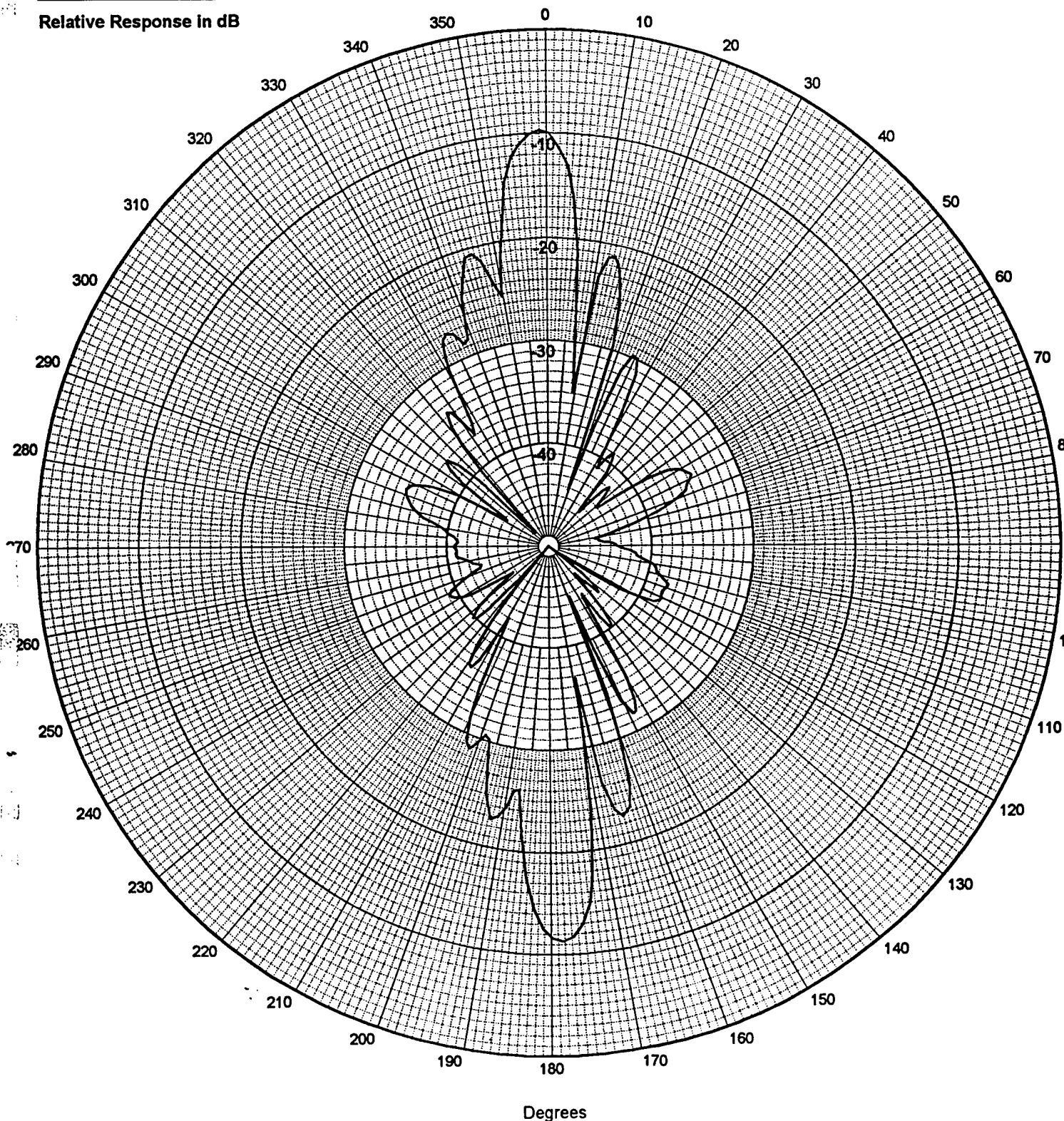
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

Relative Response in dB



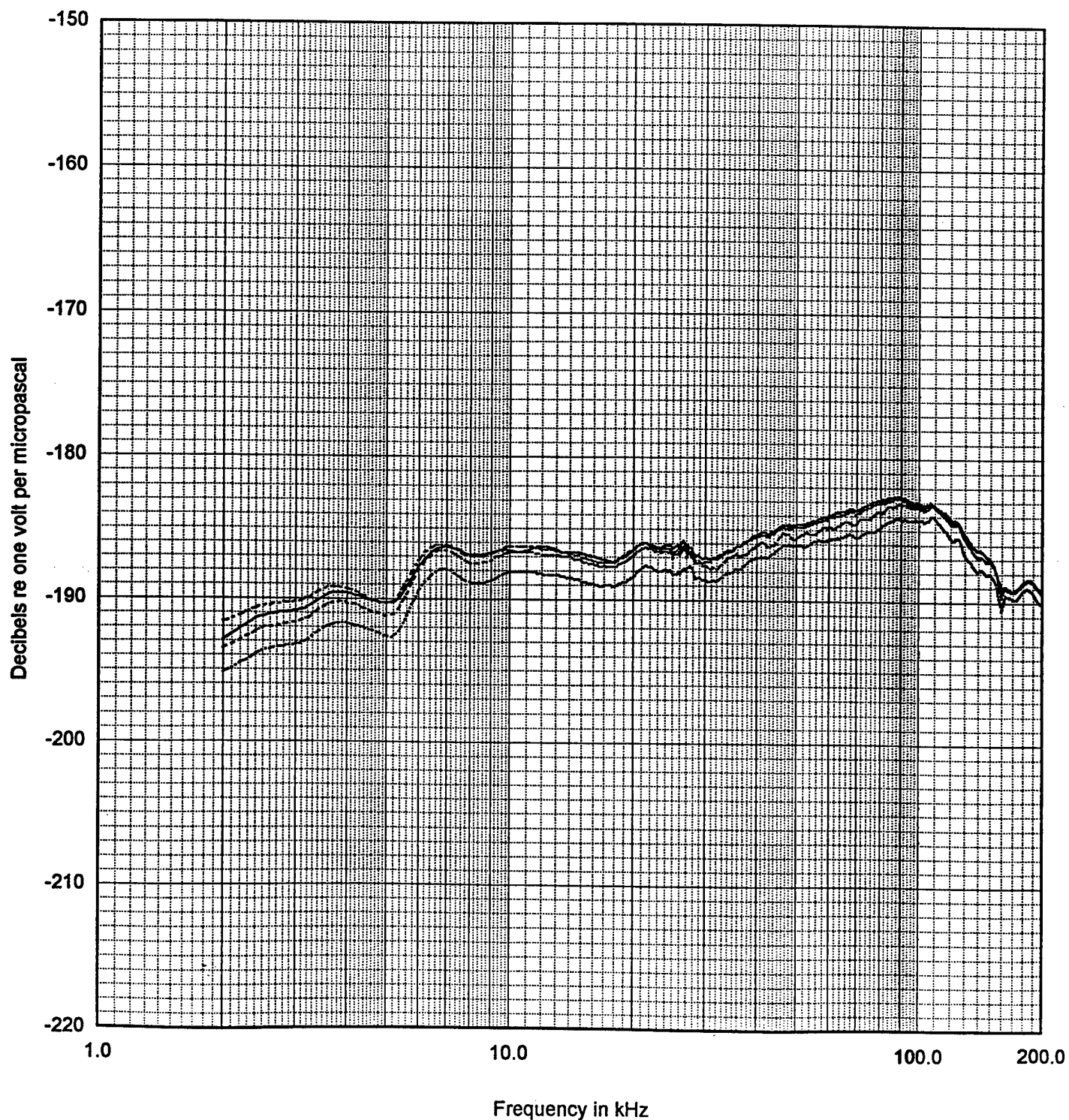
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4K-1

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure





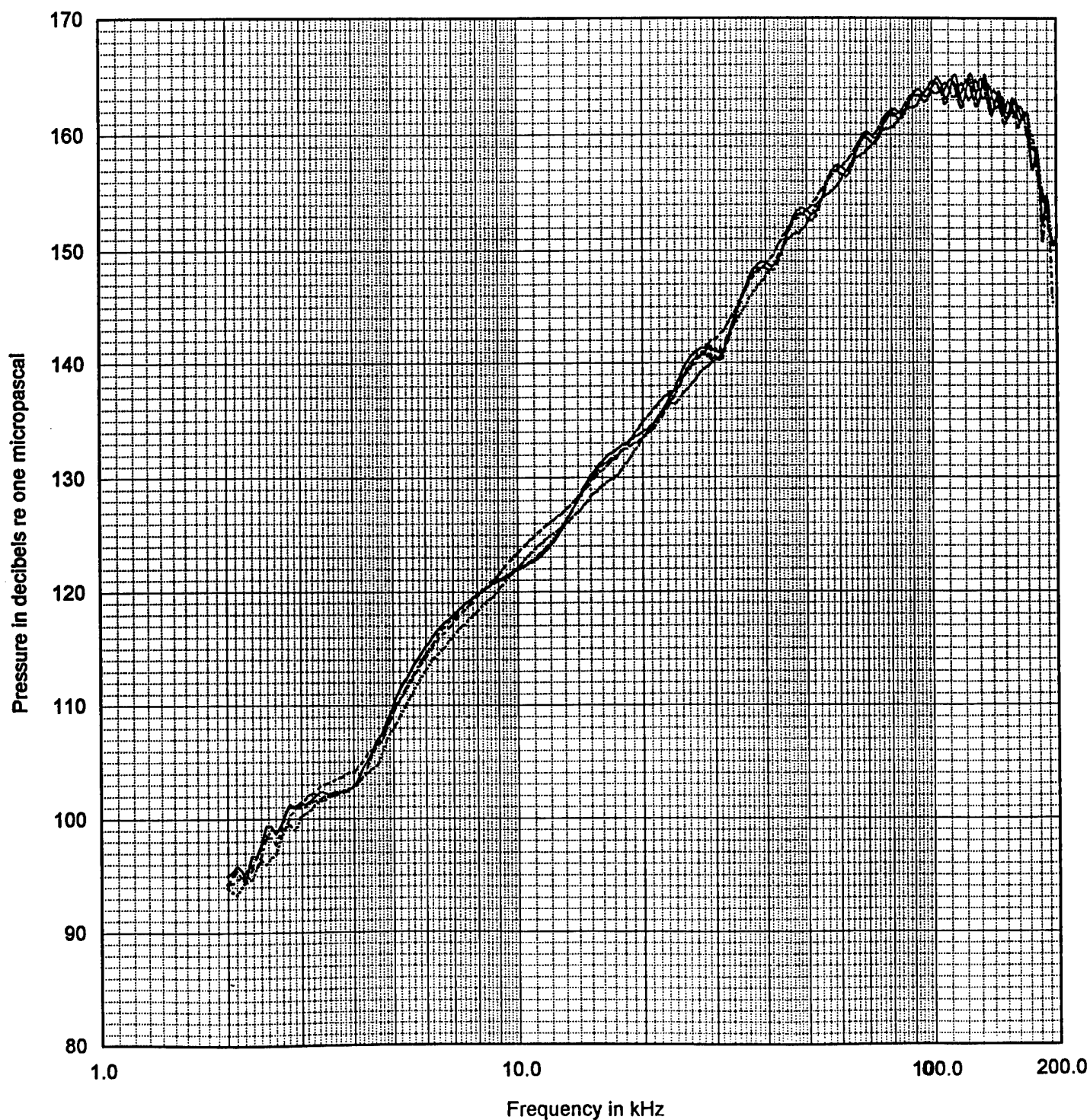
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 4K-1

Pressure at one meter per volt applied at end of cable; Unbalanced

Water Temp: 4° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 6895 kPa ( 703.1 m)  
- - - - - 16 kPa ( 1.6 m) After Pressure



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m )

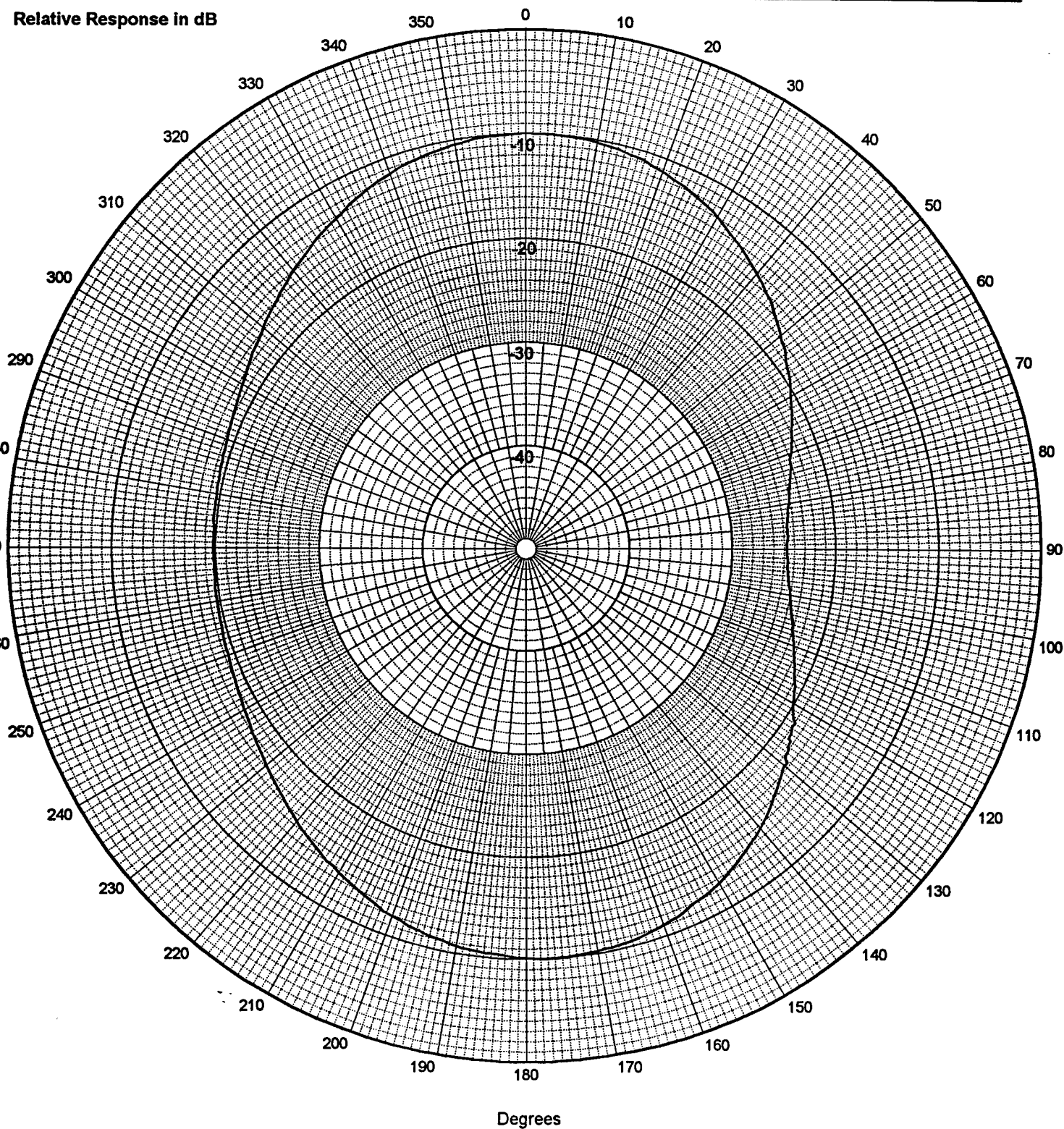
Water Temperature: 4° C

Transmit

XY Plane

10 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m )

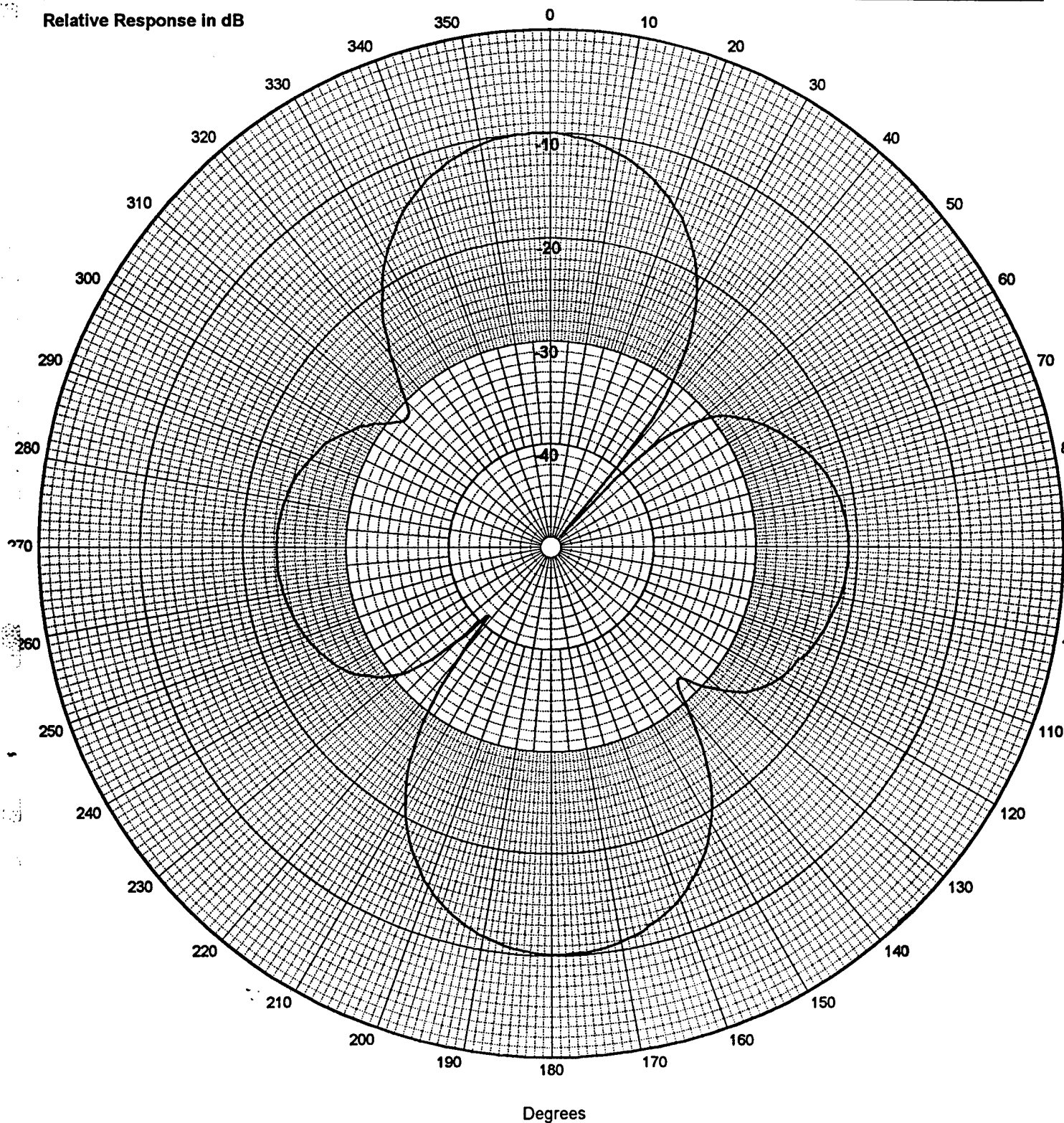
Water Temperature: 4° C

Transmit

XY Plane

20 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m )

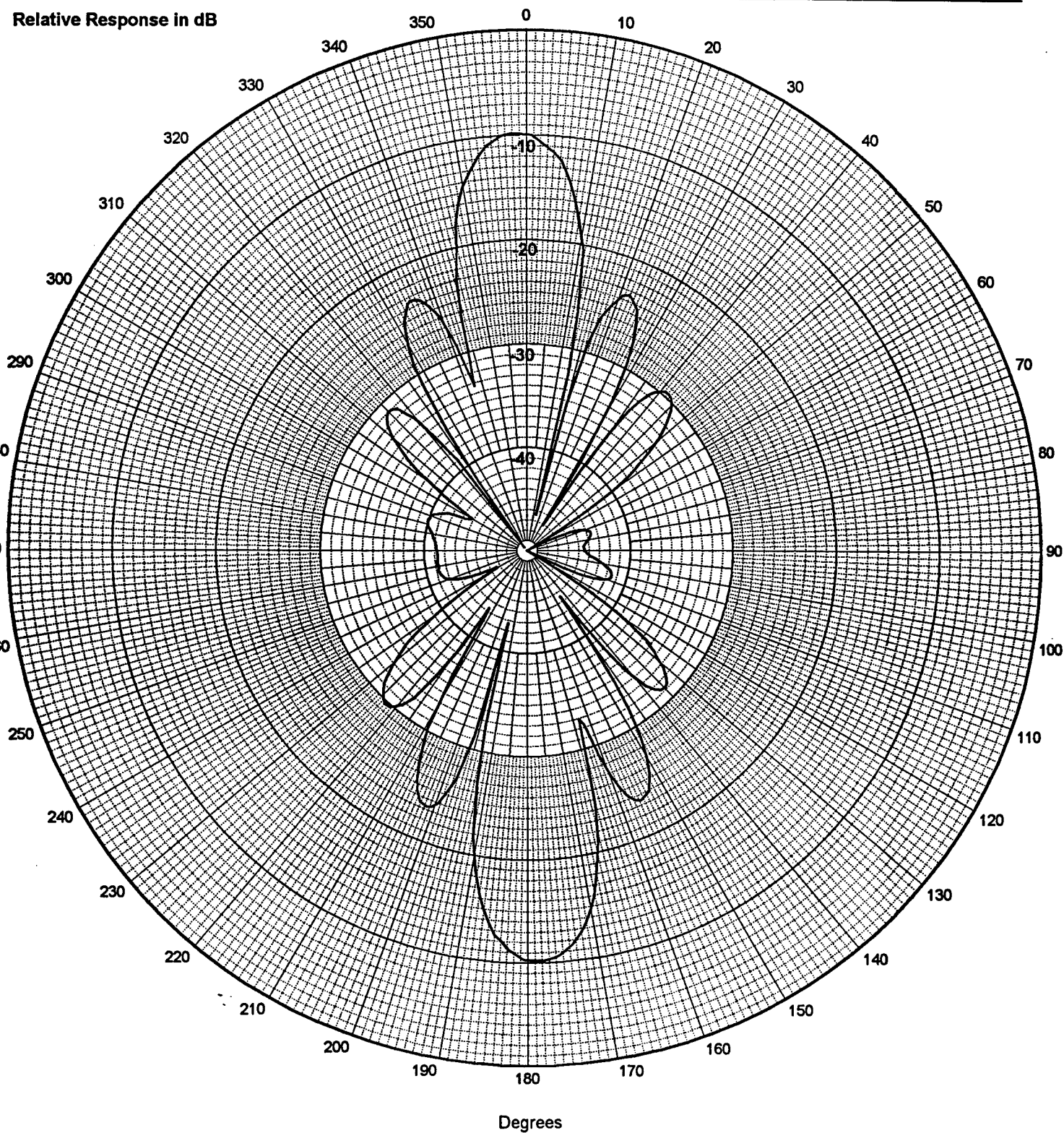
Water Temperature: 4° C

Transmit

XY Plane

50 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m )

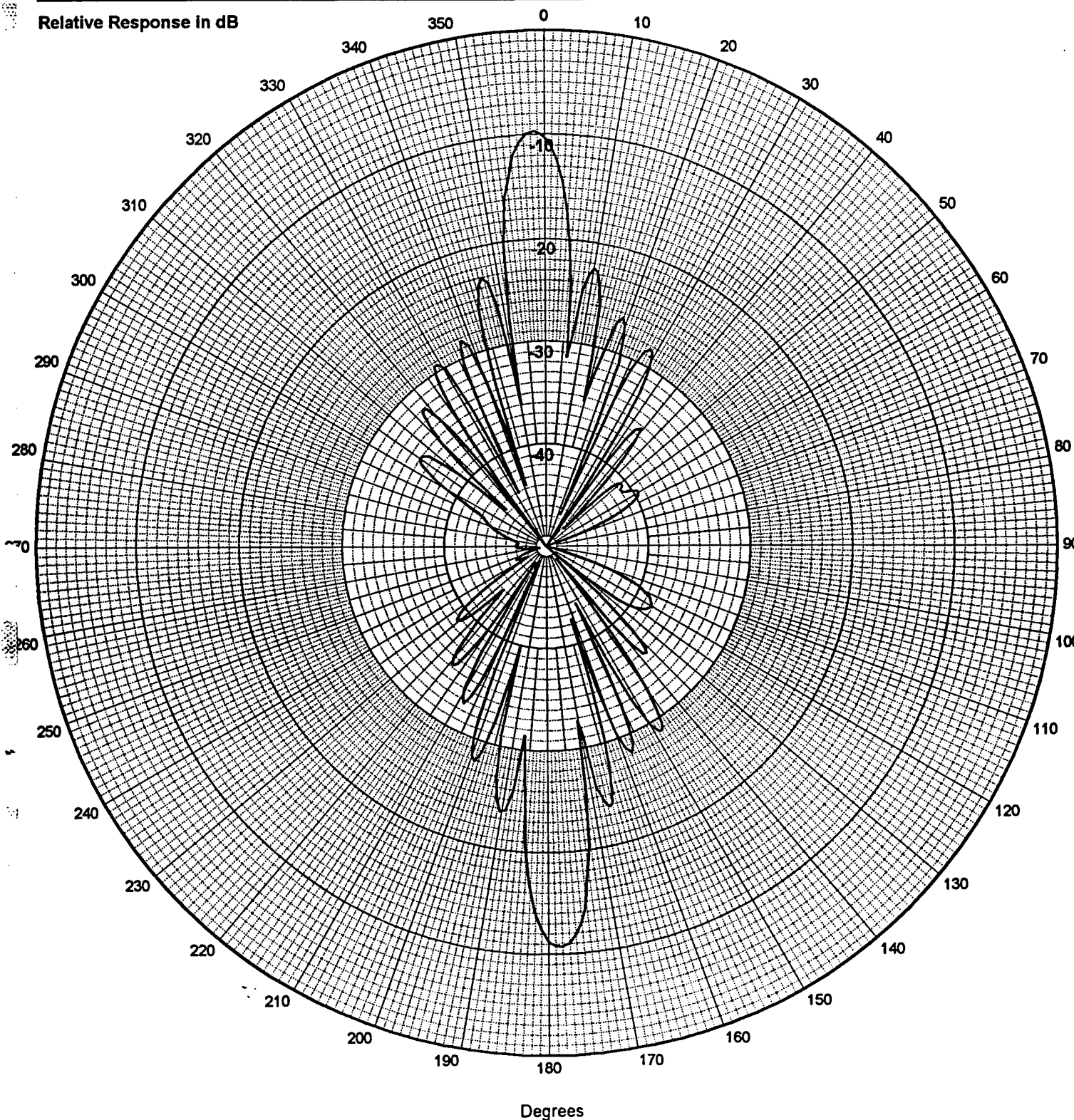
Water Temperature: 4° C

Transmit

XY Plane

100 kHz

Relative Response in dB



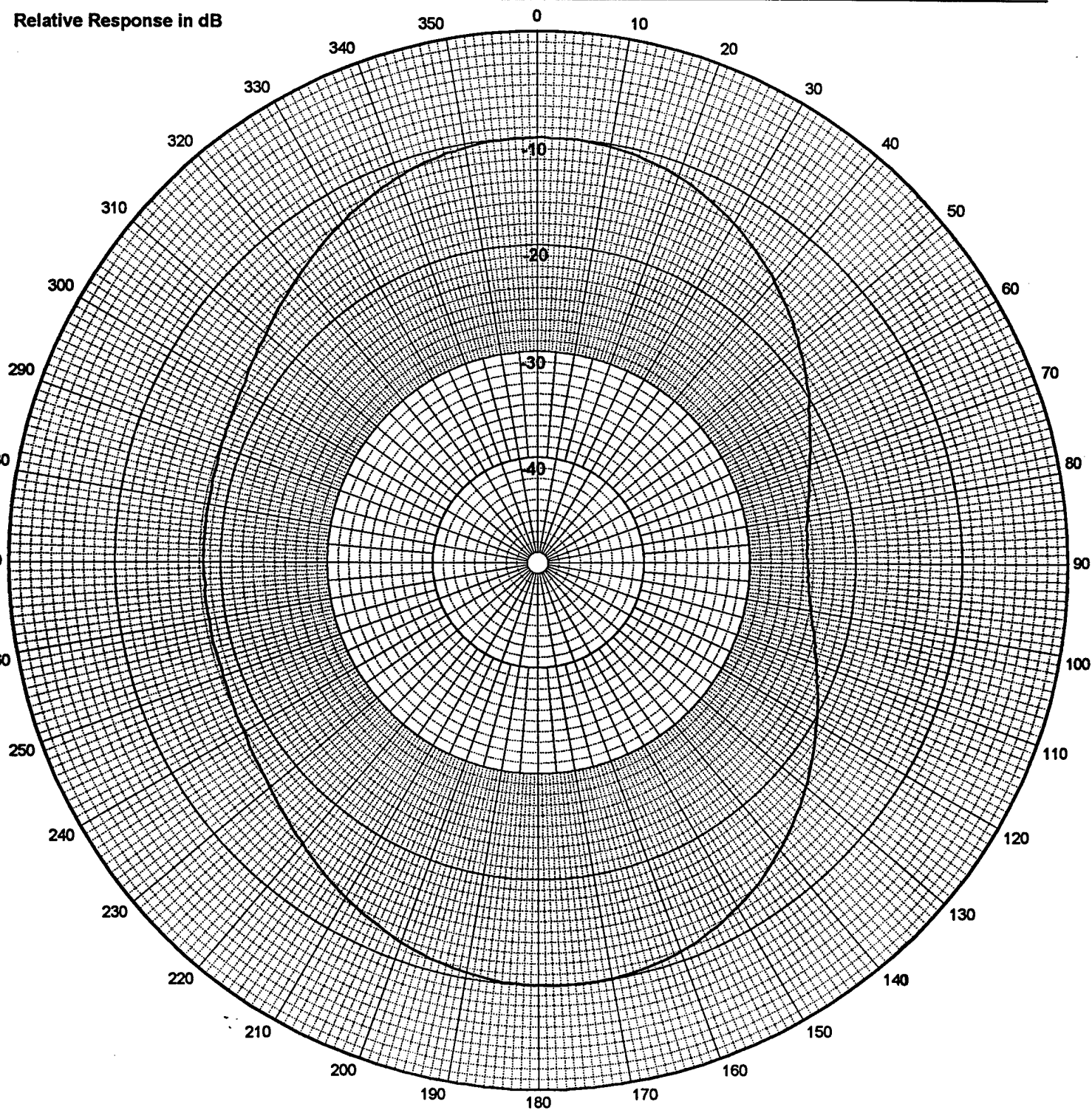
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB



Degrees

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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 3448 kPa ( 351.6 m )

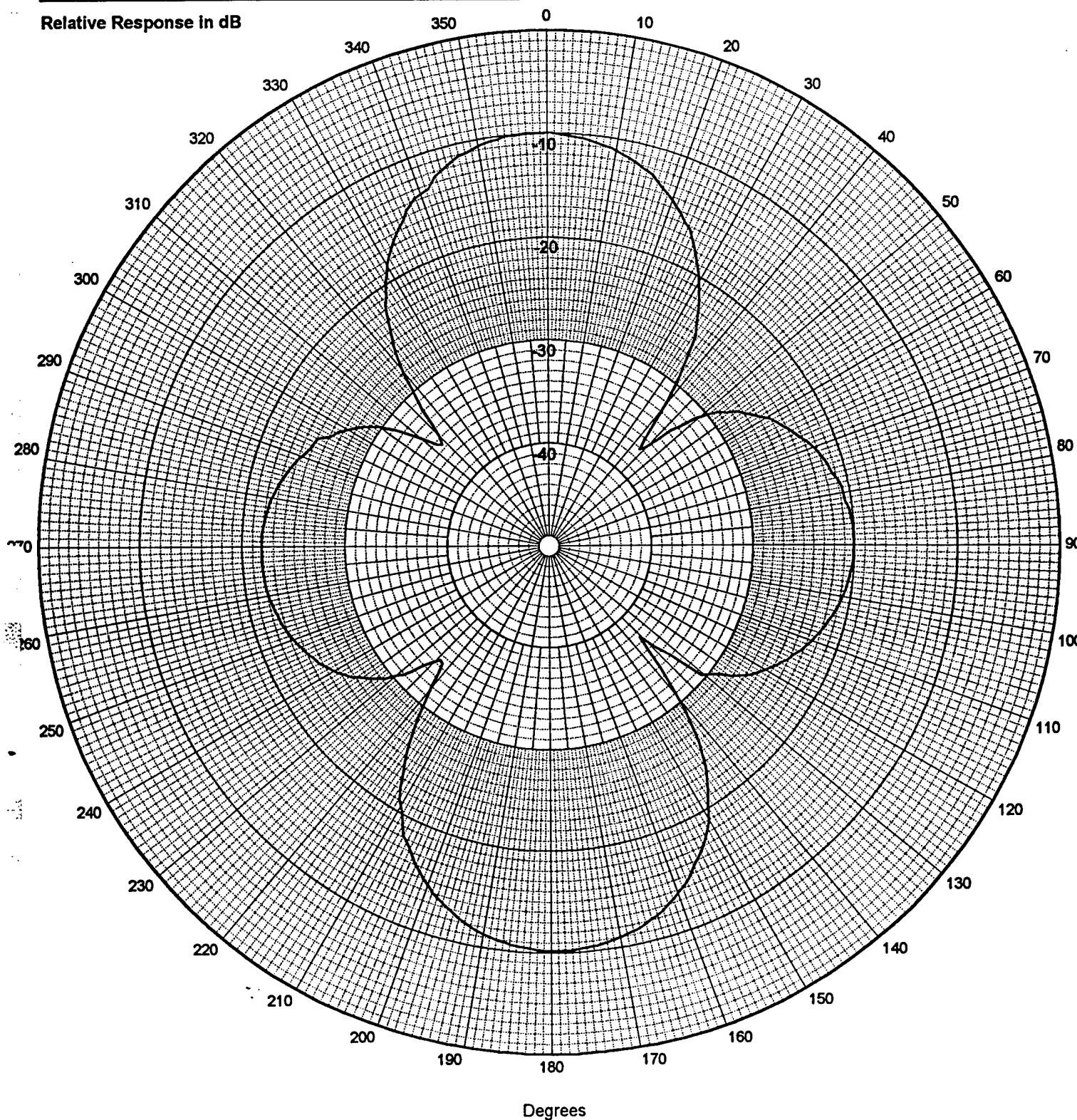
Water Temperature: 4° C

Transmit

XY Plane

20 kHz

Relative Response in dB



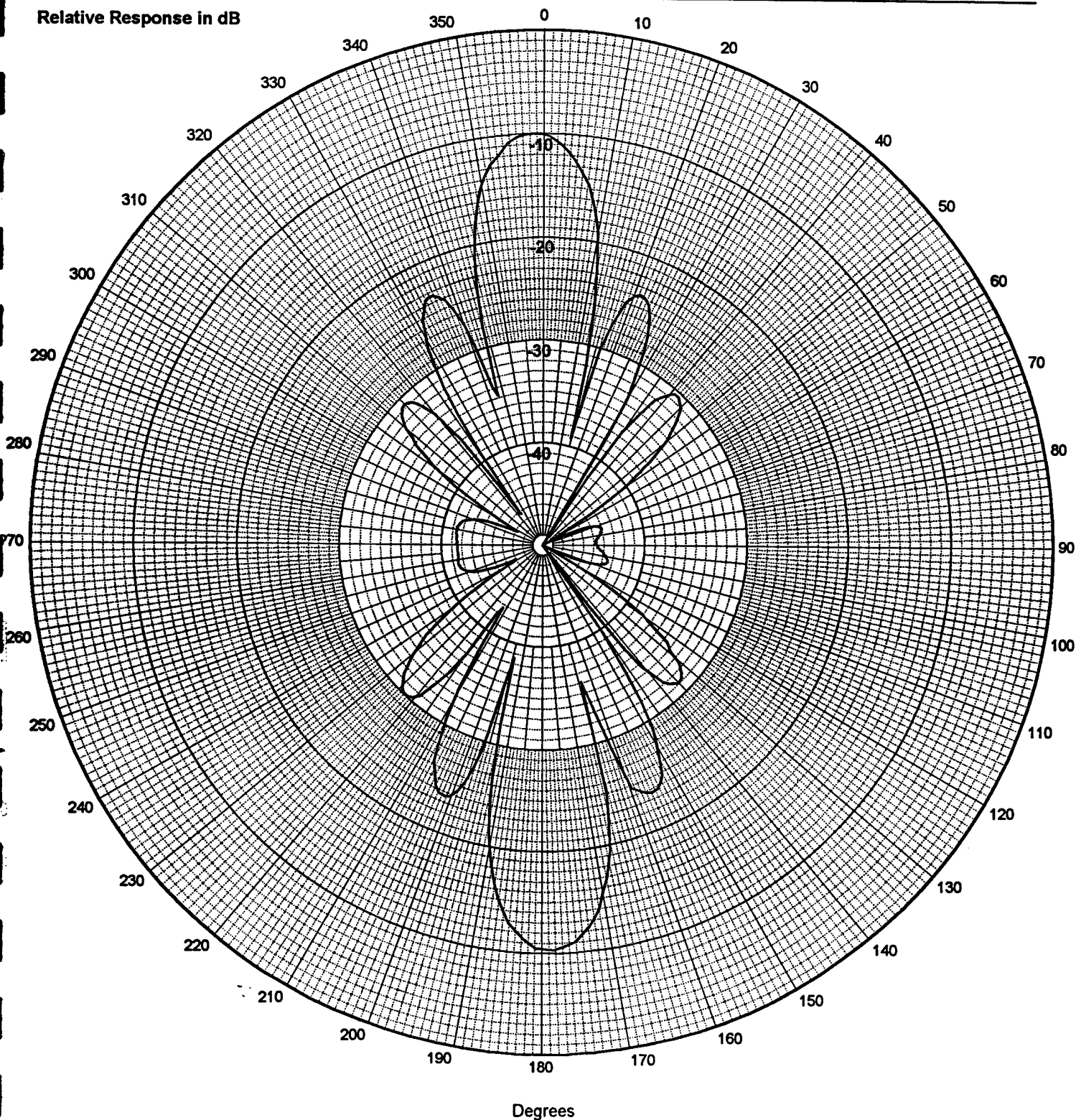
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
50 kHz

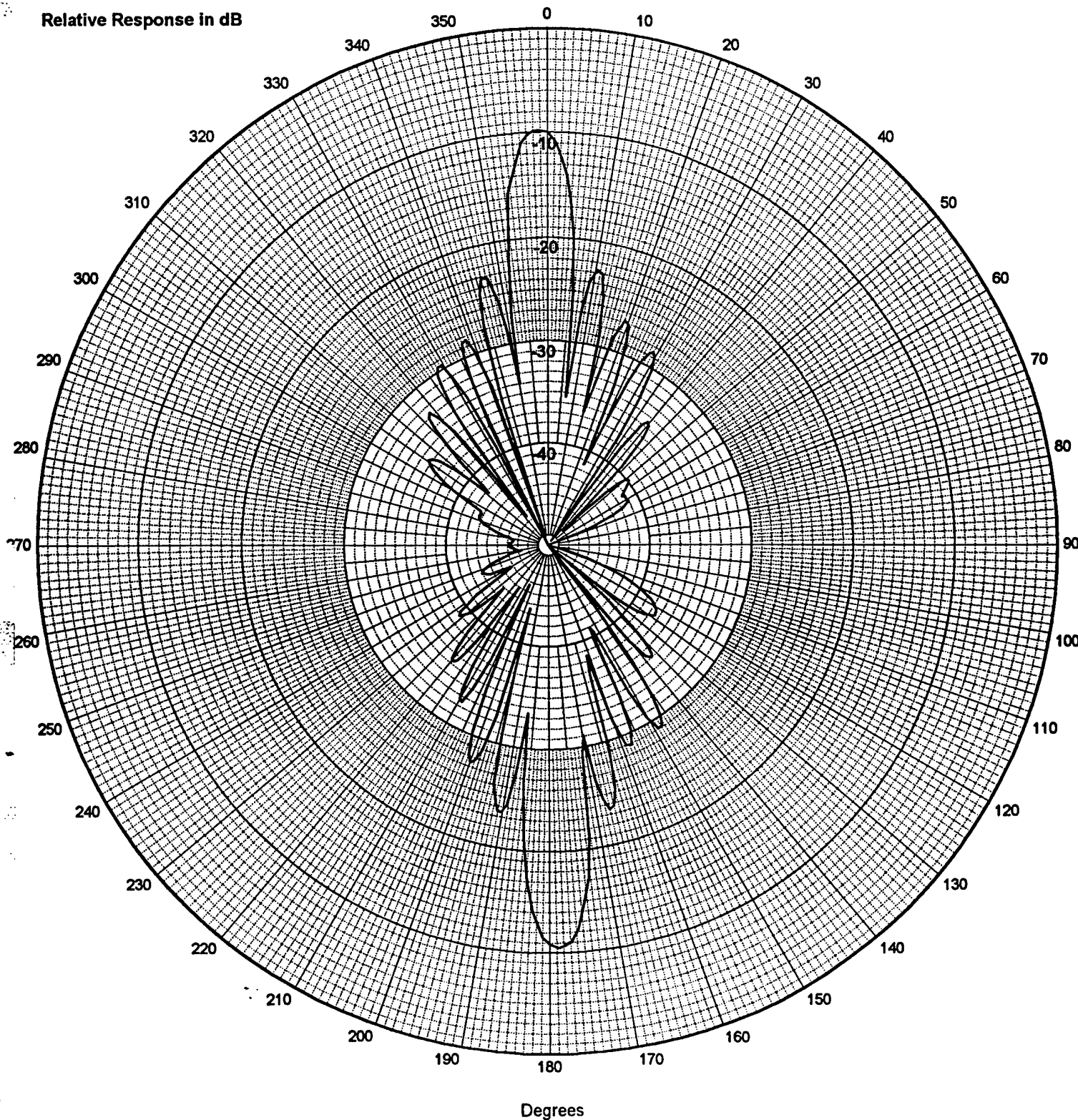
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz



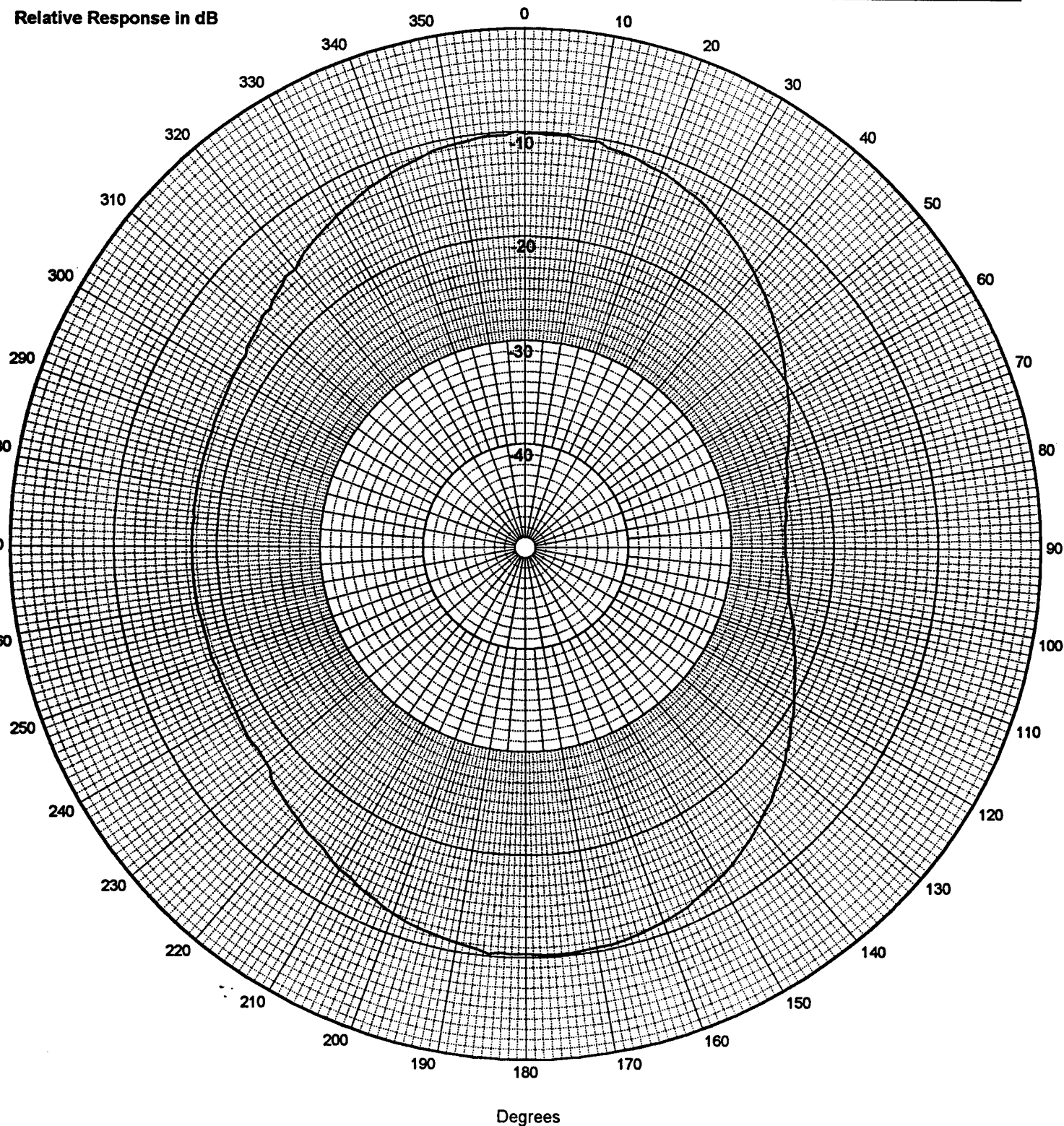
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
10 kHz

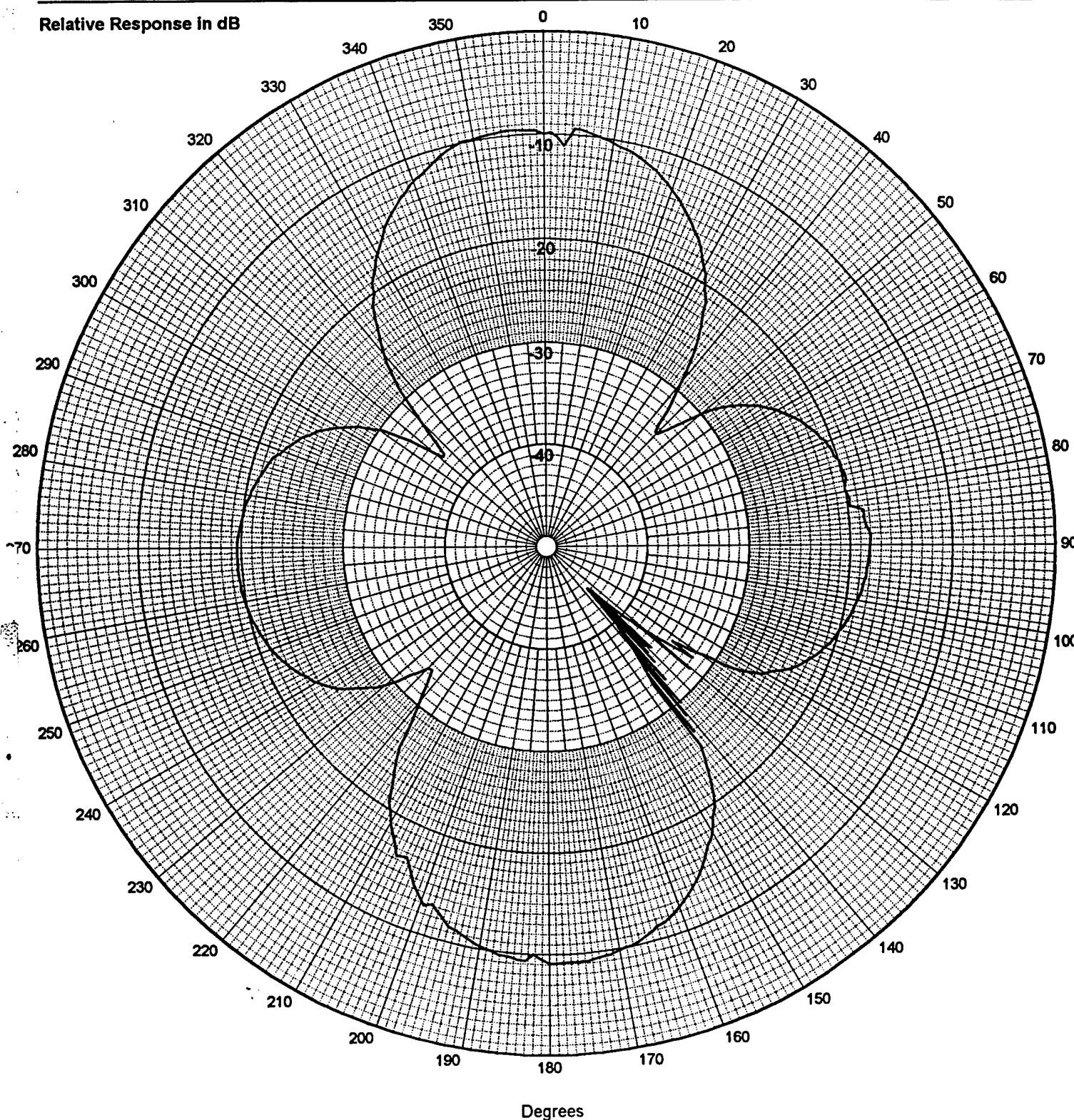
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
20 kHz

Relative Response in dB



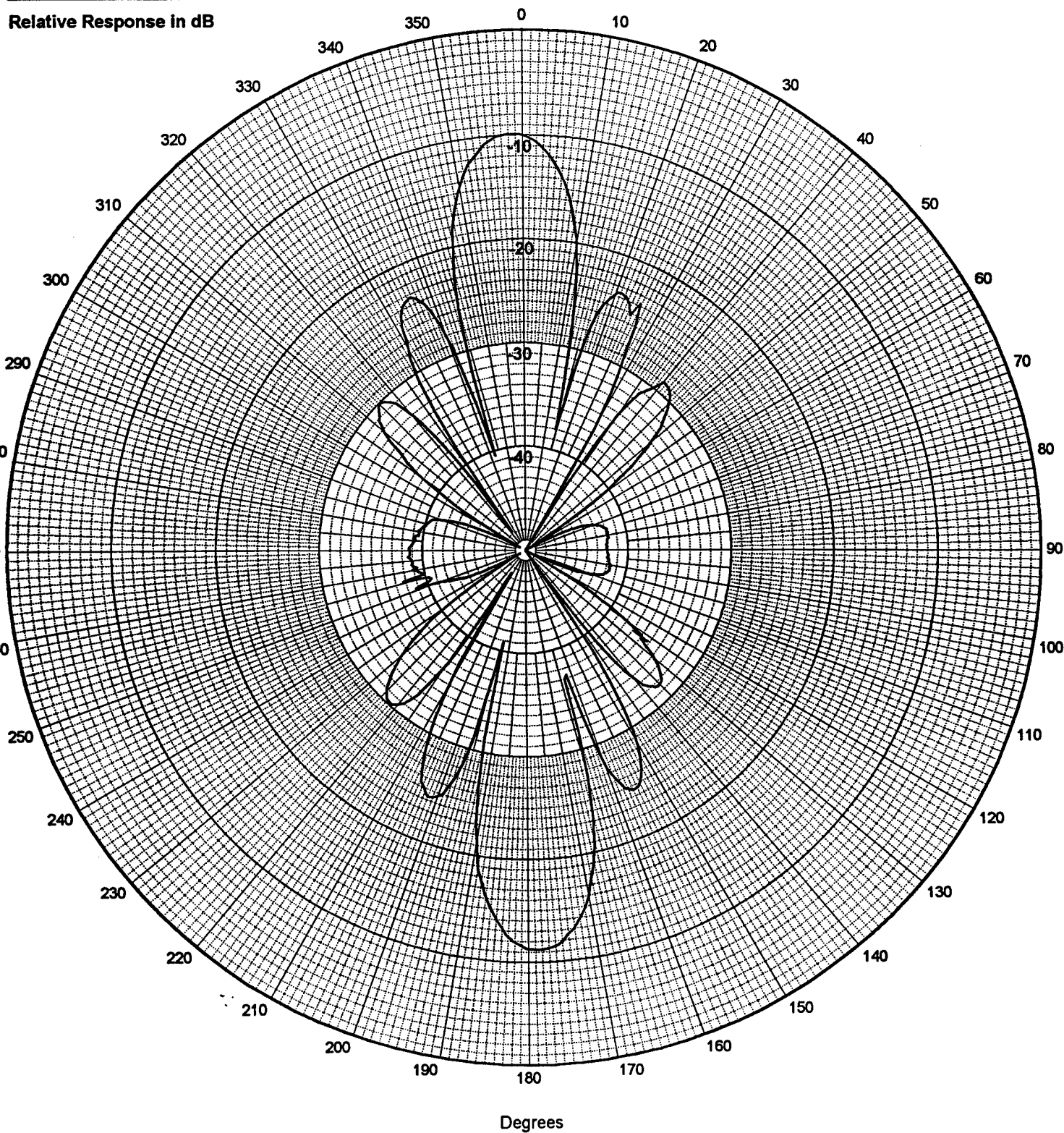
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
50 kHz

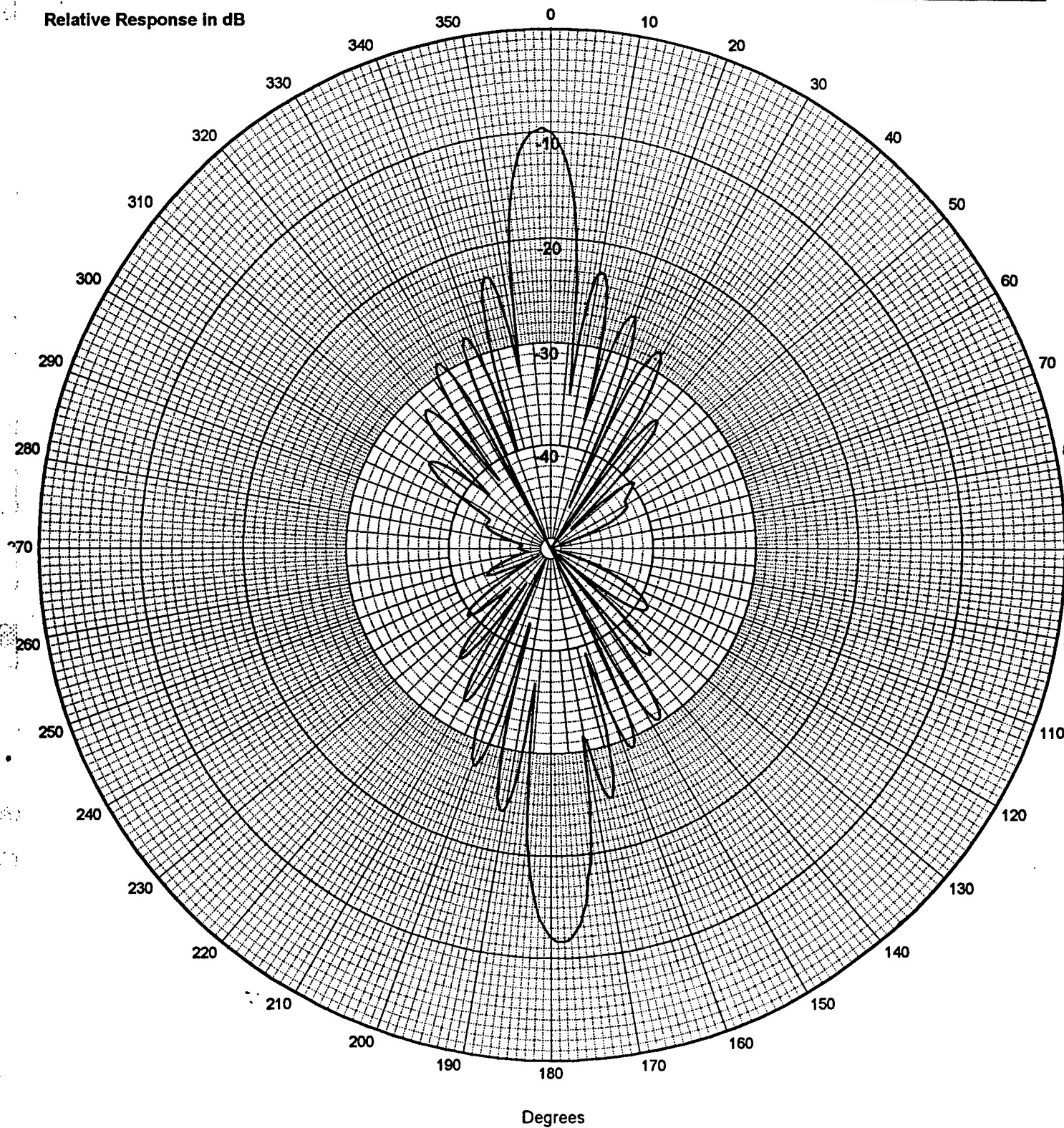
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 4° C  
Transmit  
XY Plane  
100 kHz



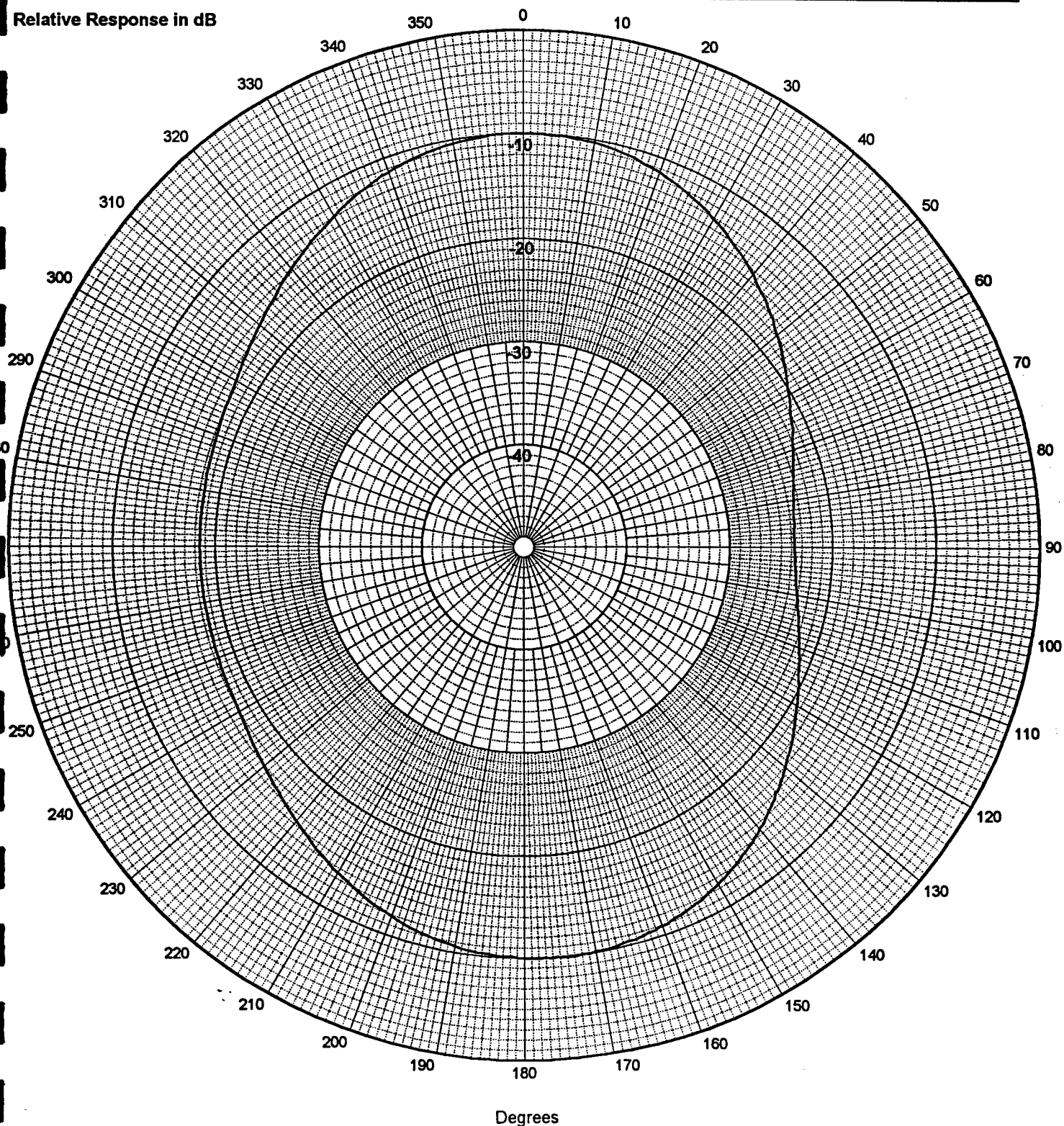
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
10 kHz

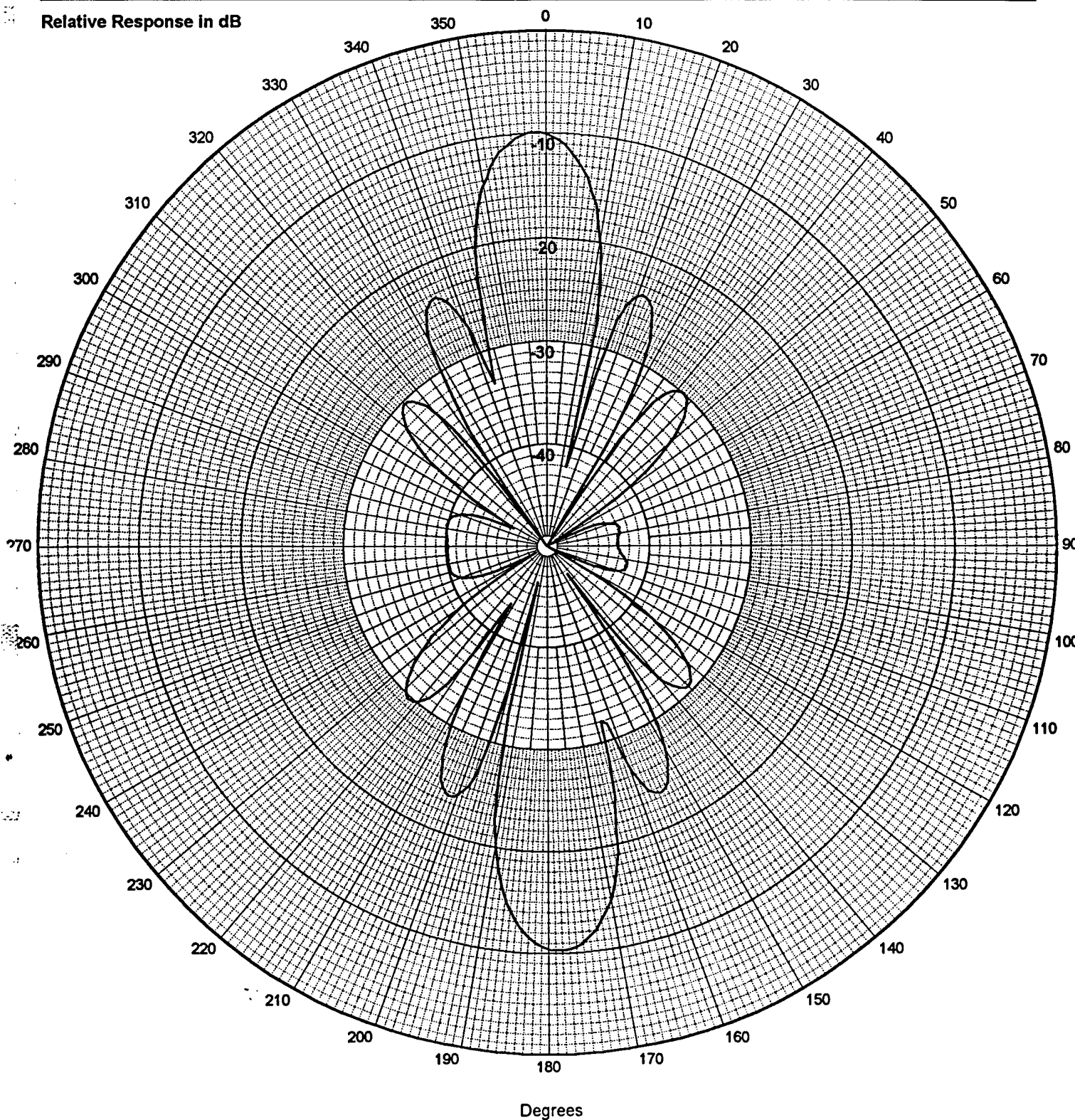
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 4° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

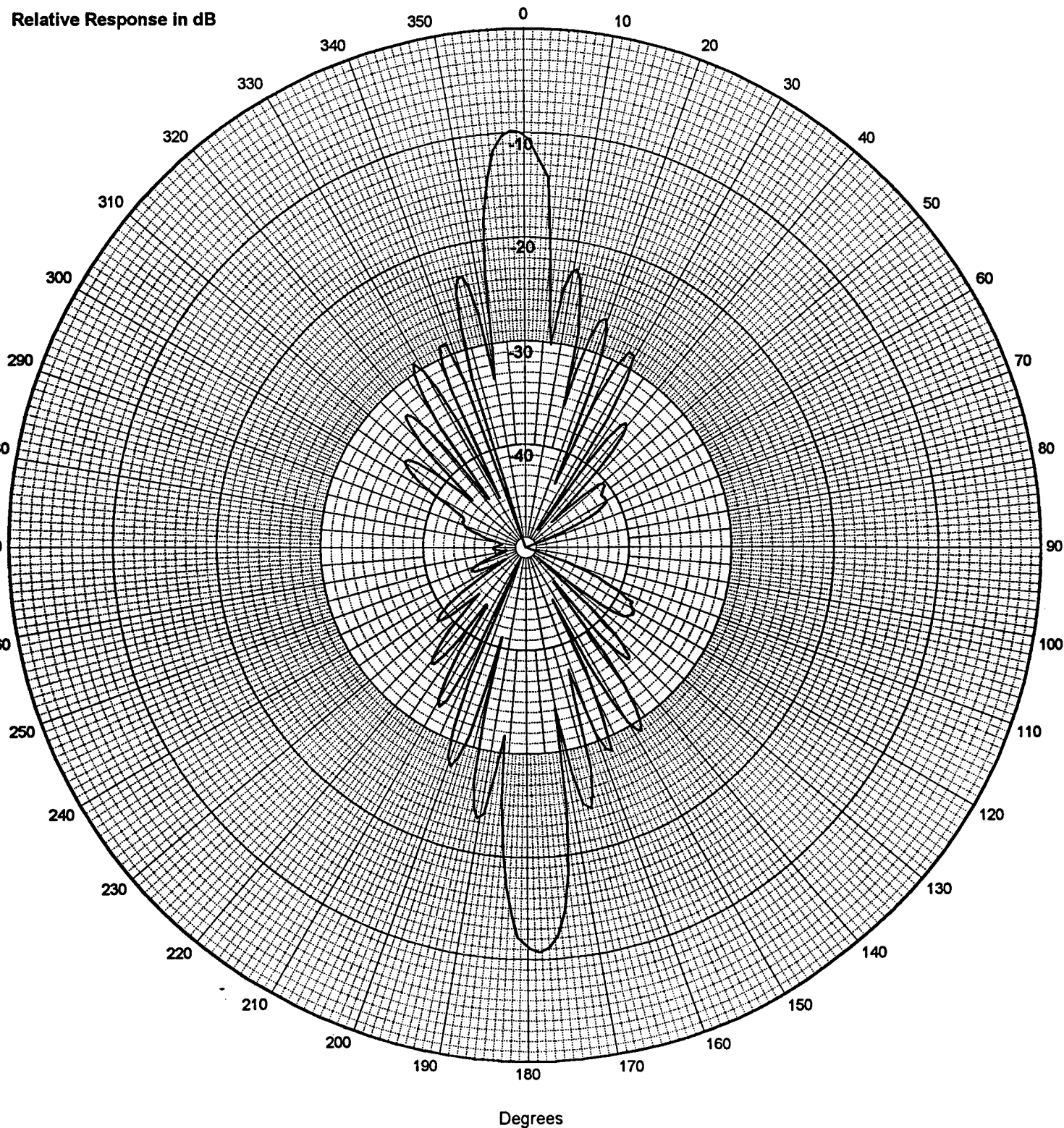
Water Temperature: 4° C

Transmit

XY Plane

100 kHz

Relative Response in dB





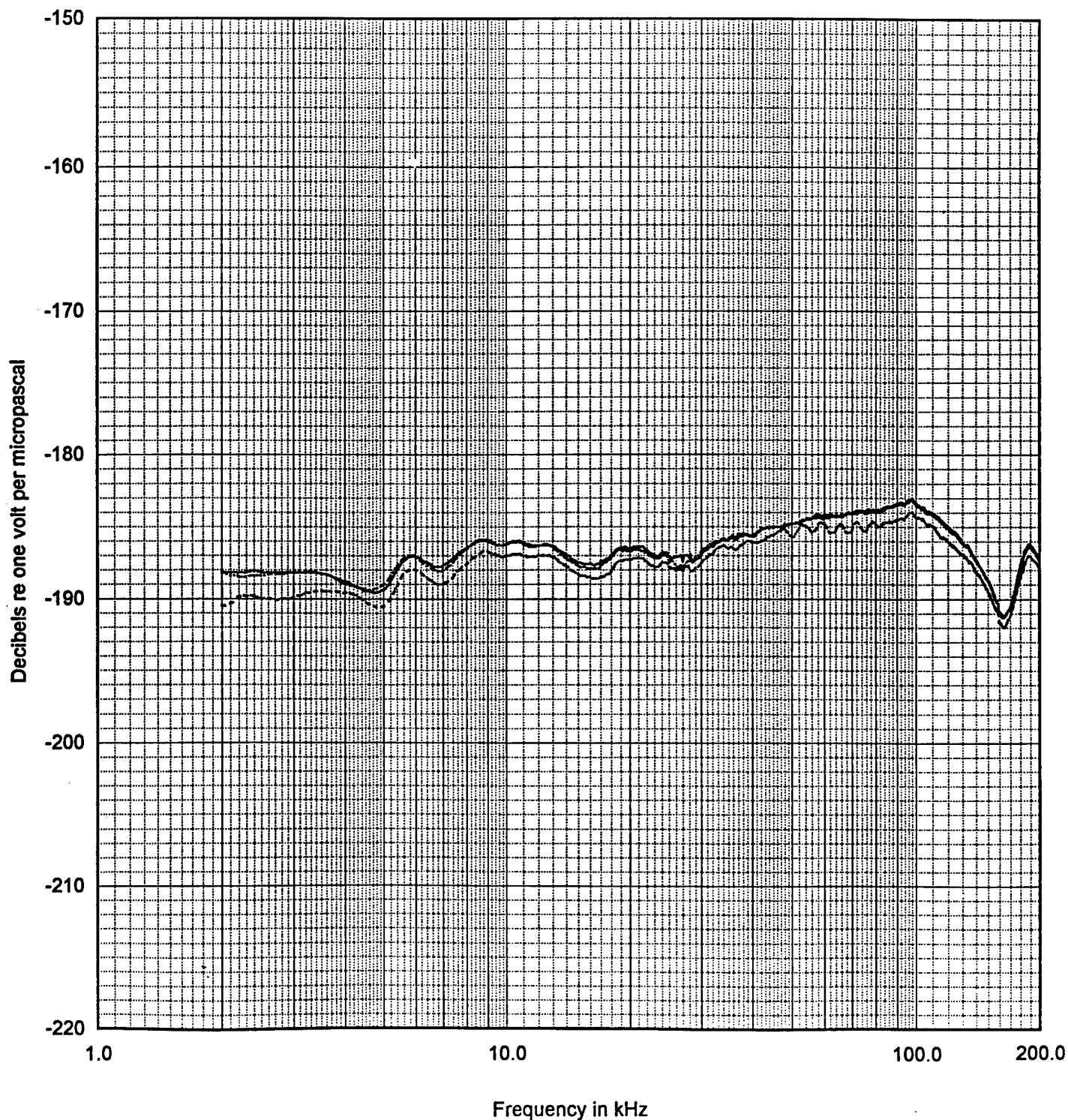
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4K-1

Open-circuit voltage measured at end of 15 m cable; Unbalanced

Water Temp: 22° C

———— 16 kPa ( 1.6 m) Before Pressure  
----- 3448 kPa ( 351.6 m)  
..... 16 kPa ( 1.6 m) After Pressure



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m )

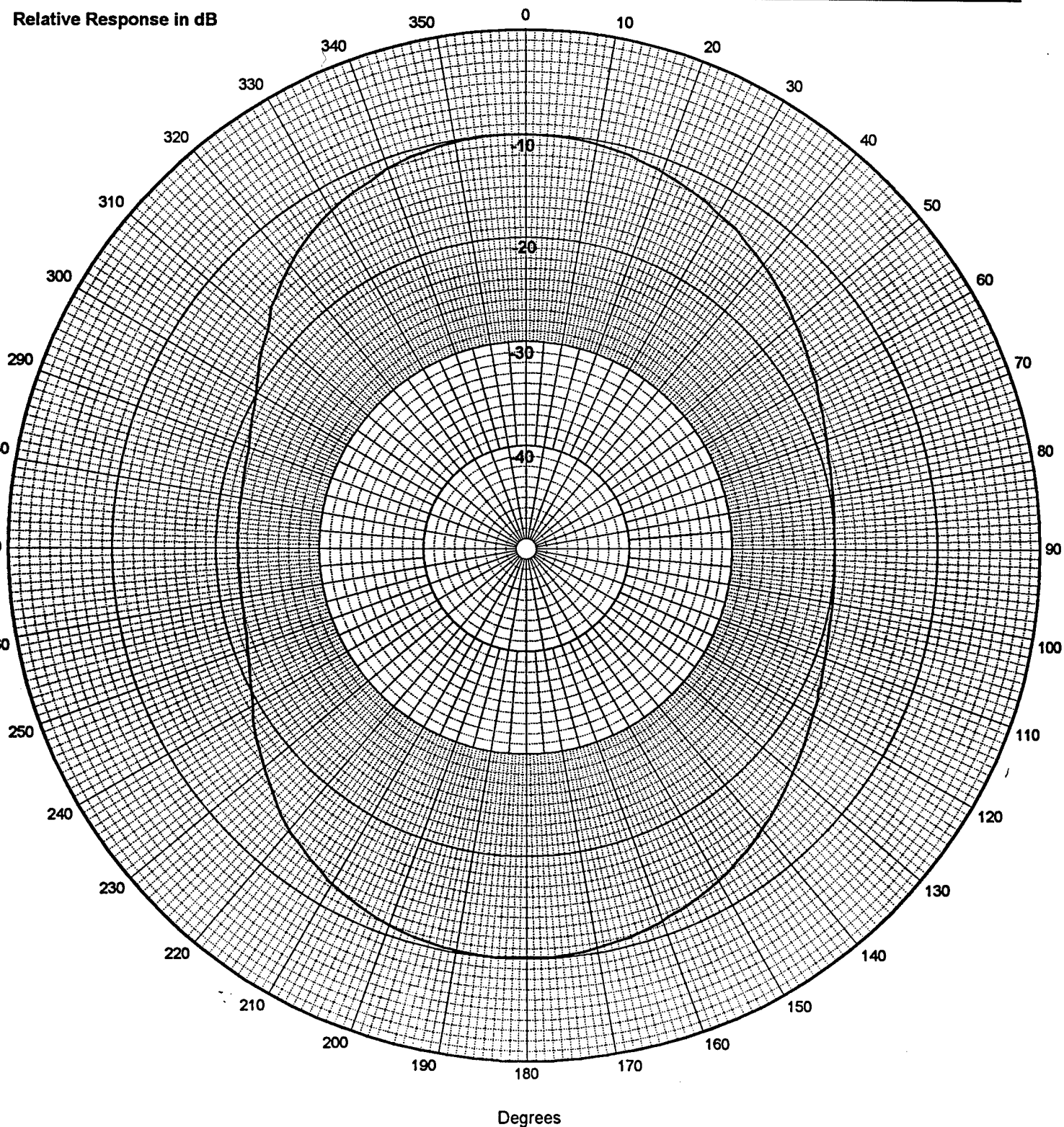
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m )

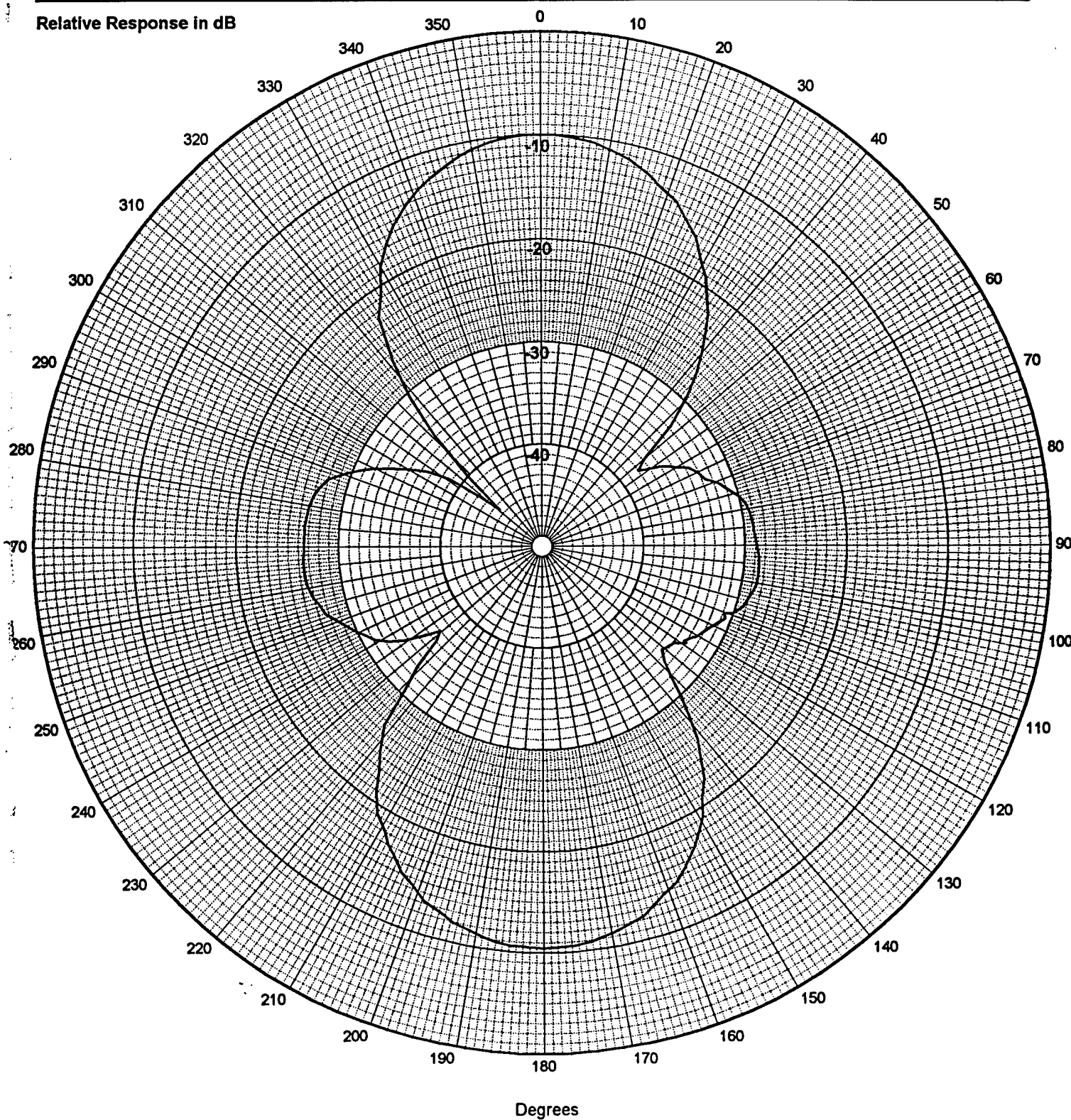
Water Temperature: 22° C

Transmit

XY Plane

20 kHz

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 16 kPa ( 1.6 m )

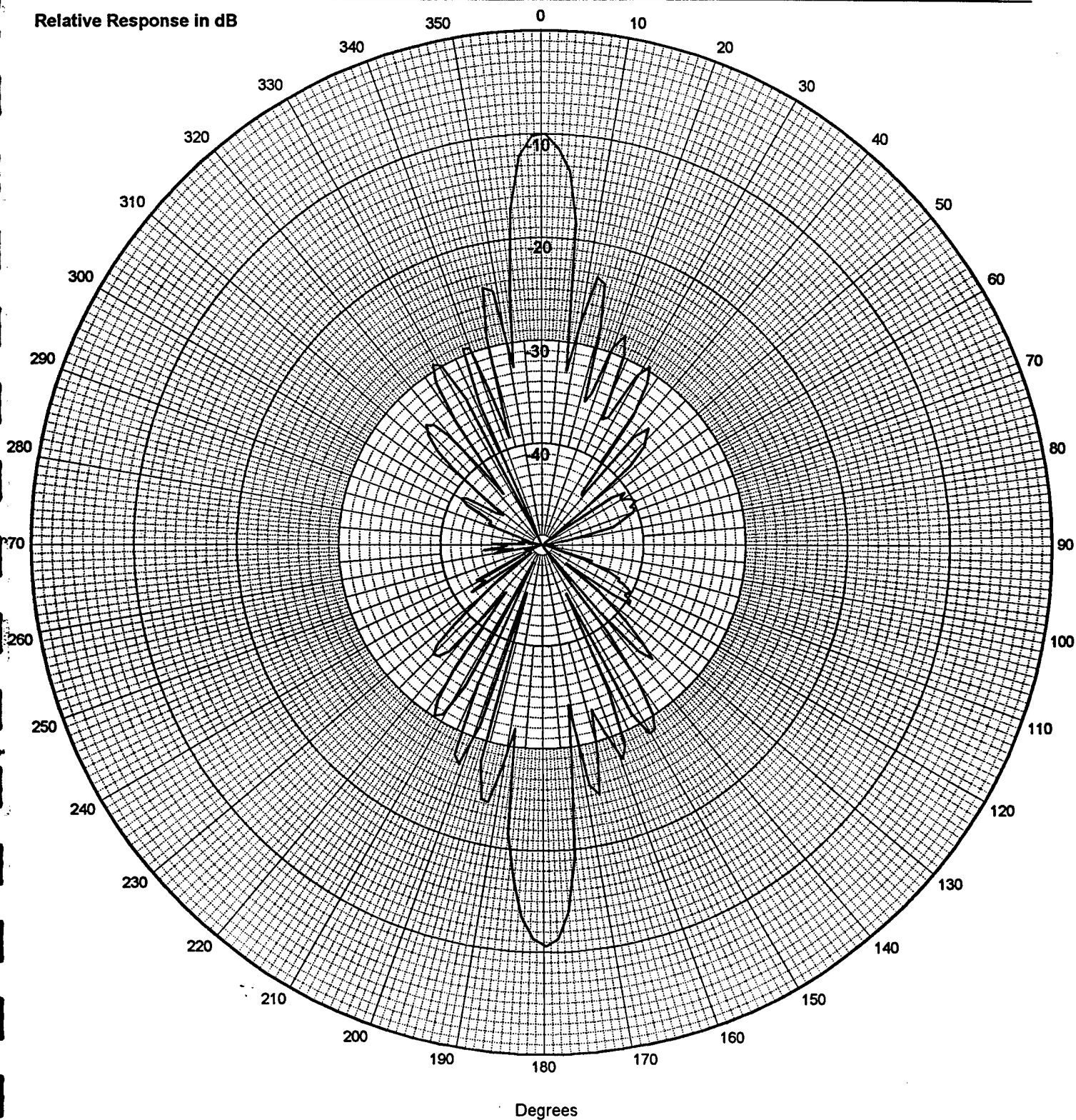
Water Temperature: 22° C

Transmit

XY Plane

100 kHz

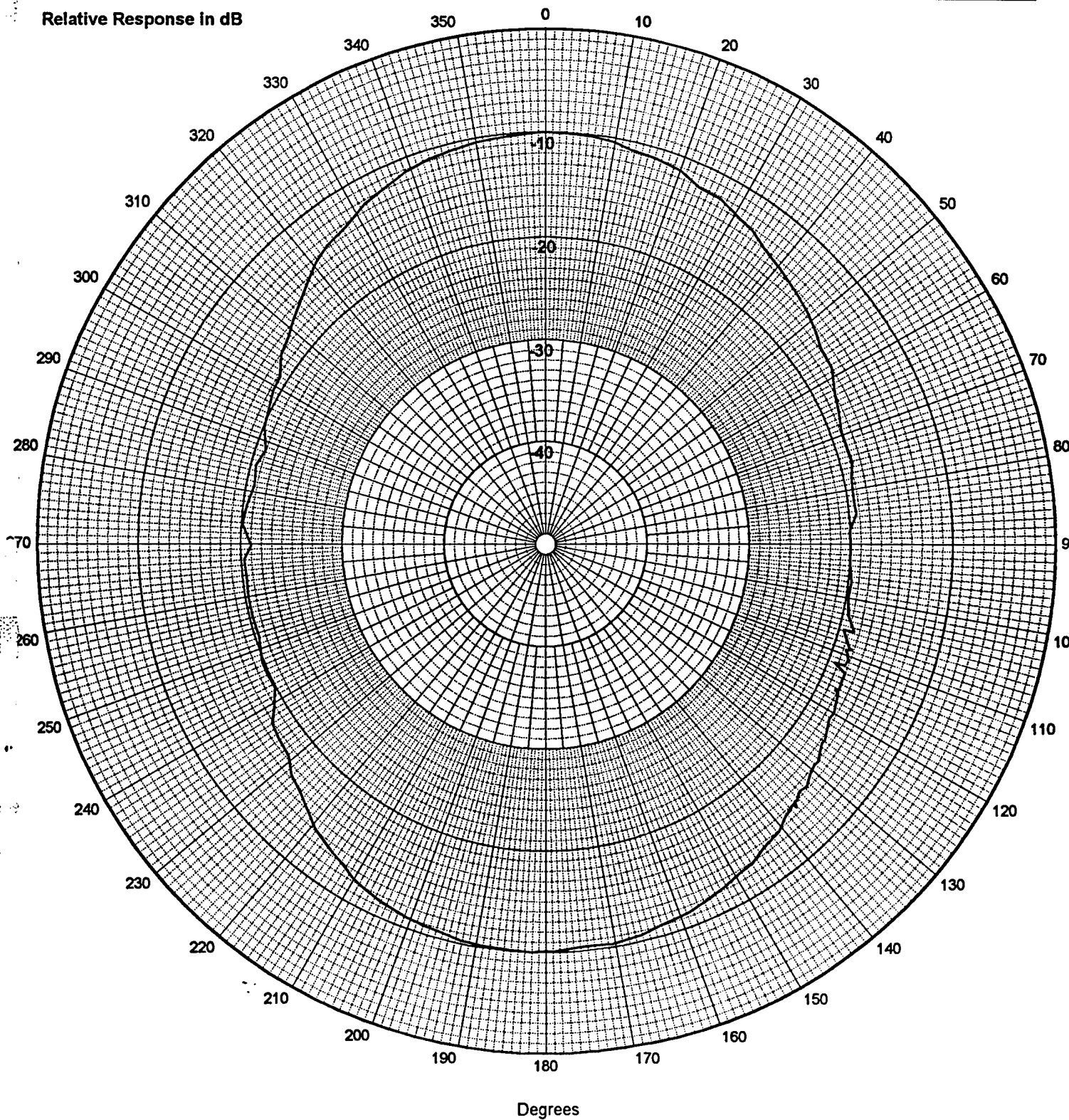
Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz



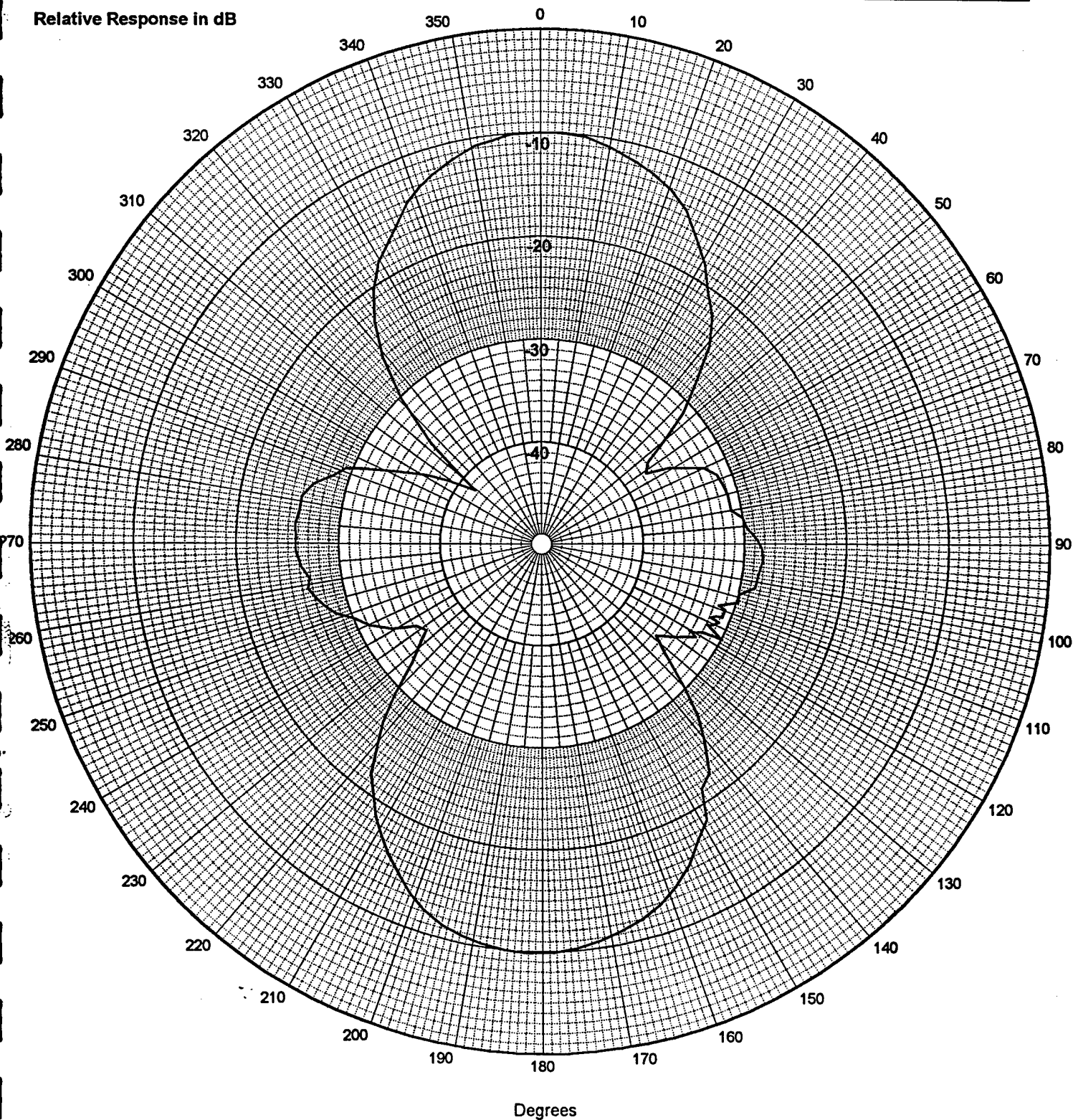
NAVAL UNDERSEA WARFARE CENTER  
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P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0779-111  
ANECHOIC TANK FACILITY  
APR 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

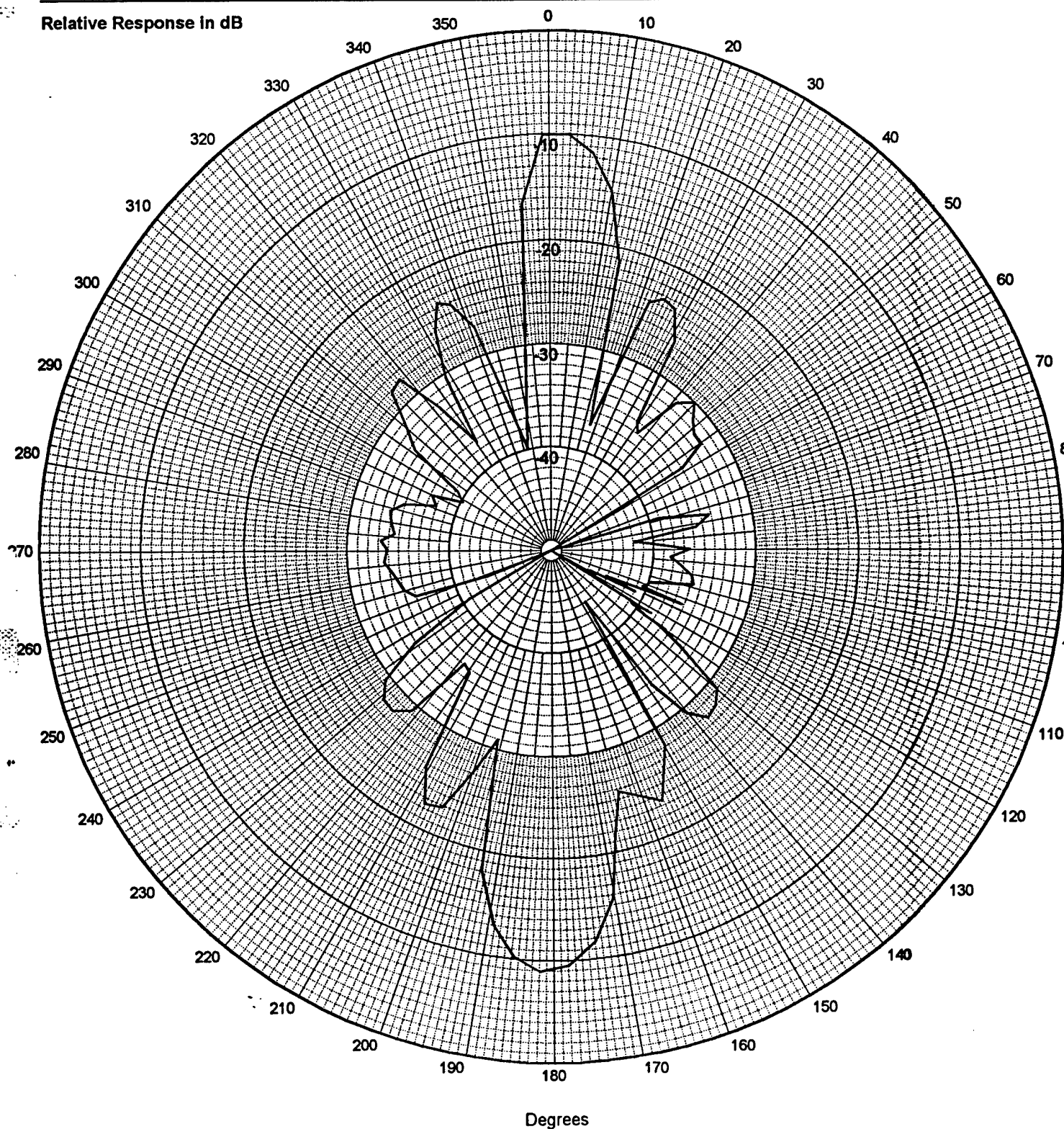
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



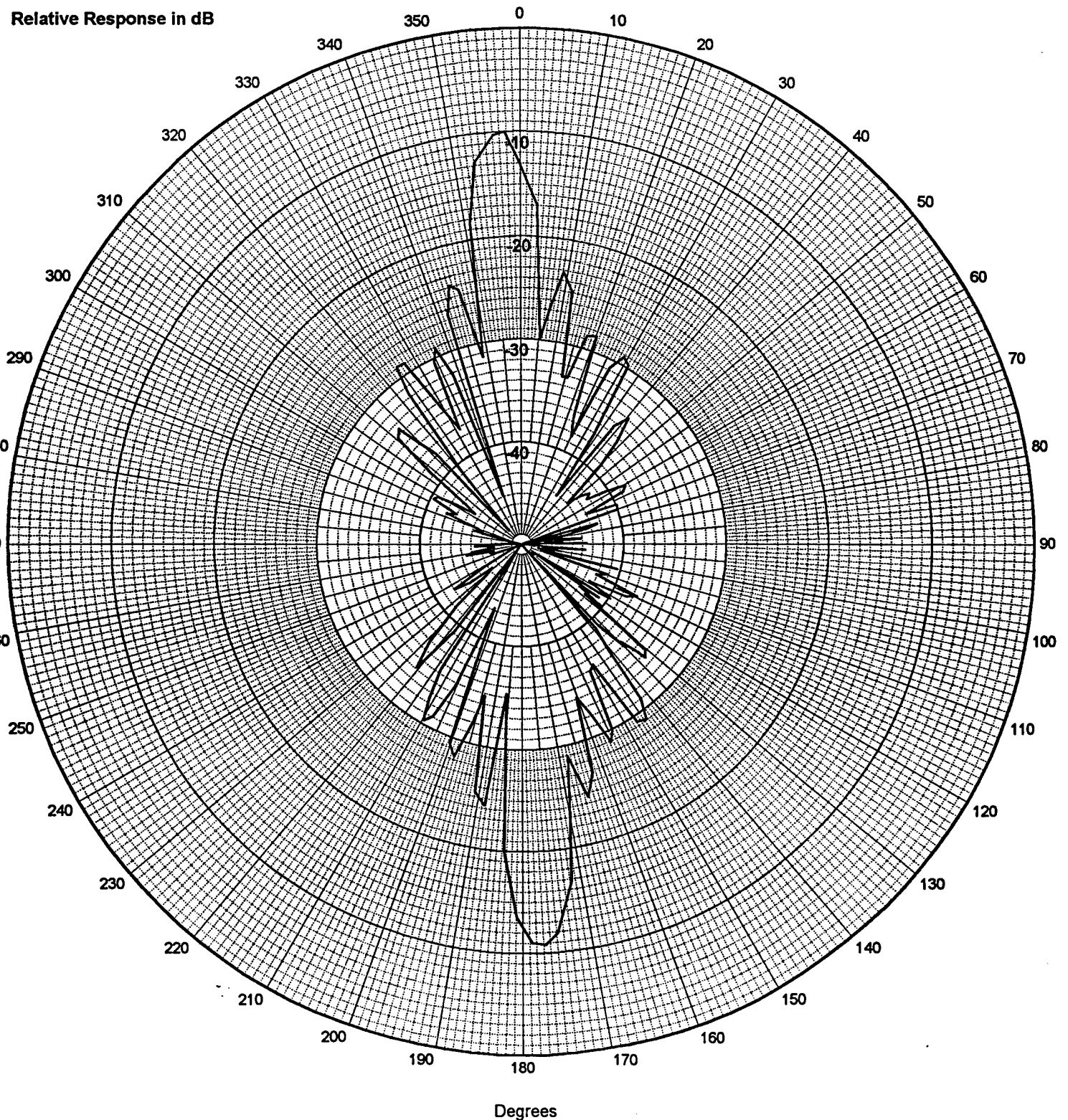
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0779-113  
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 3448 kPa ( 351.6 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1

Hydrostatic Pressure: 6895 kPa ( 703.1 m )

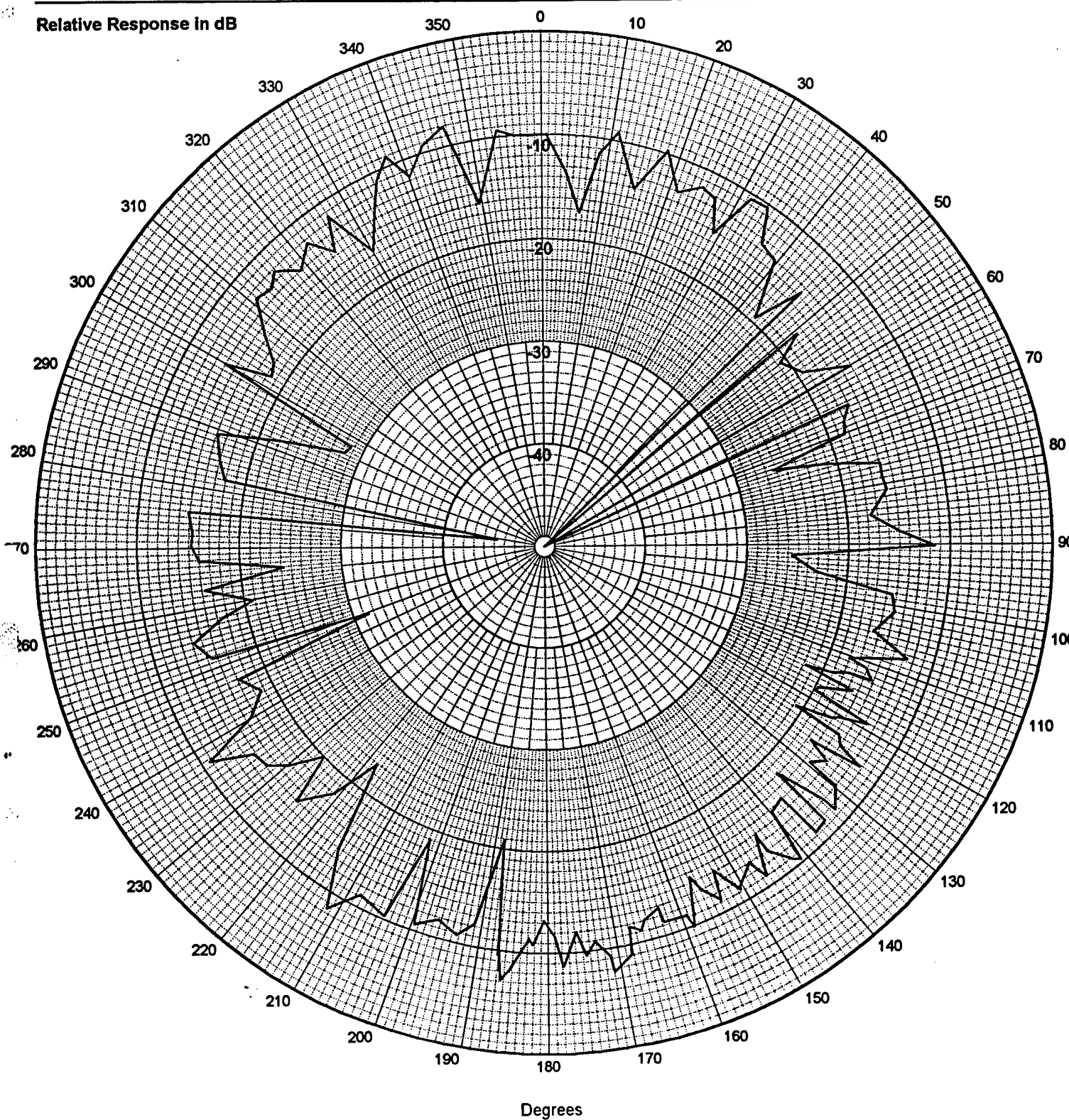
Water Temperature: 22° C

Transmit

XY Plane

10 kHz

Relative Response in dB



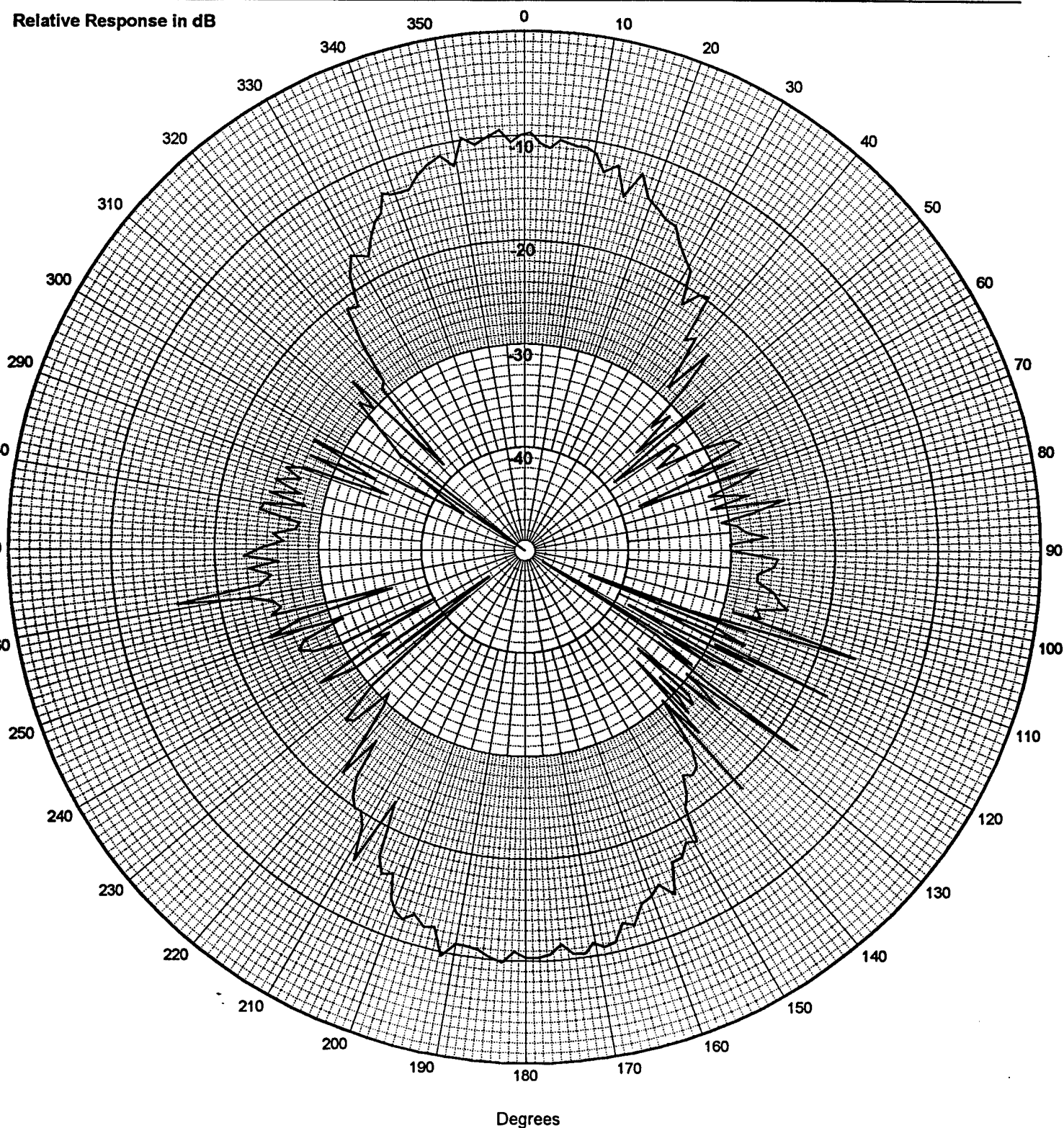
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO. 0779-115  
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
20 kHz

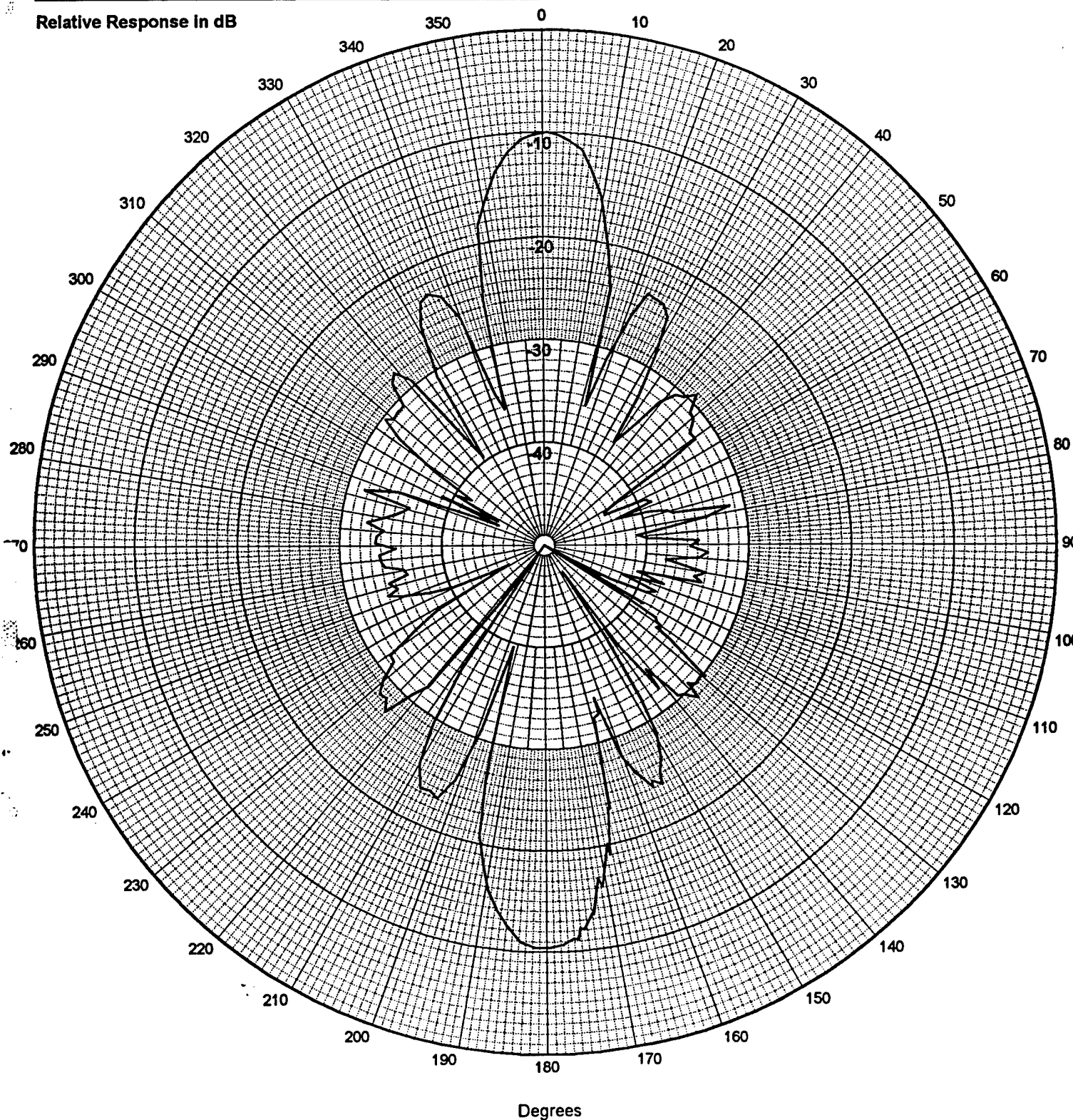
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
50 kHz

Relative Response in dB



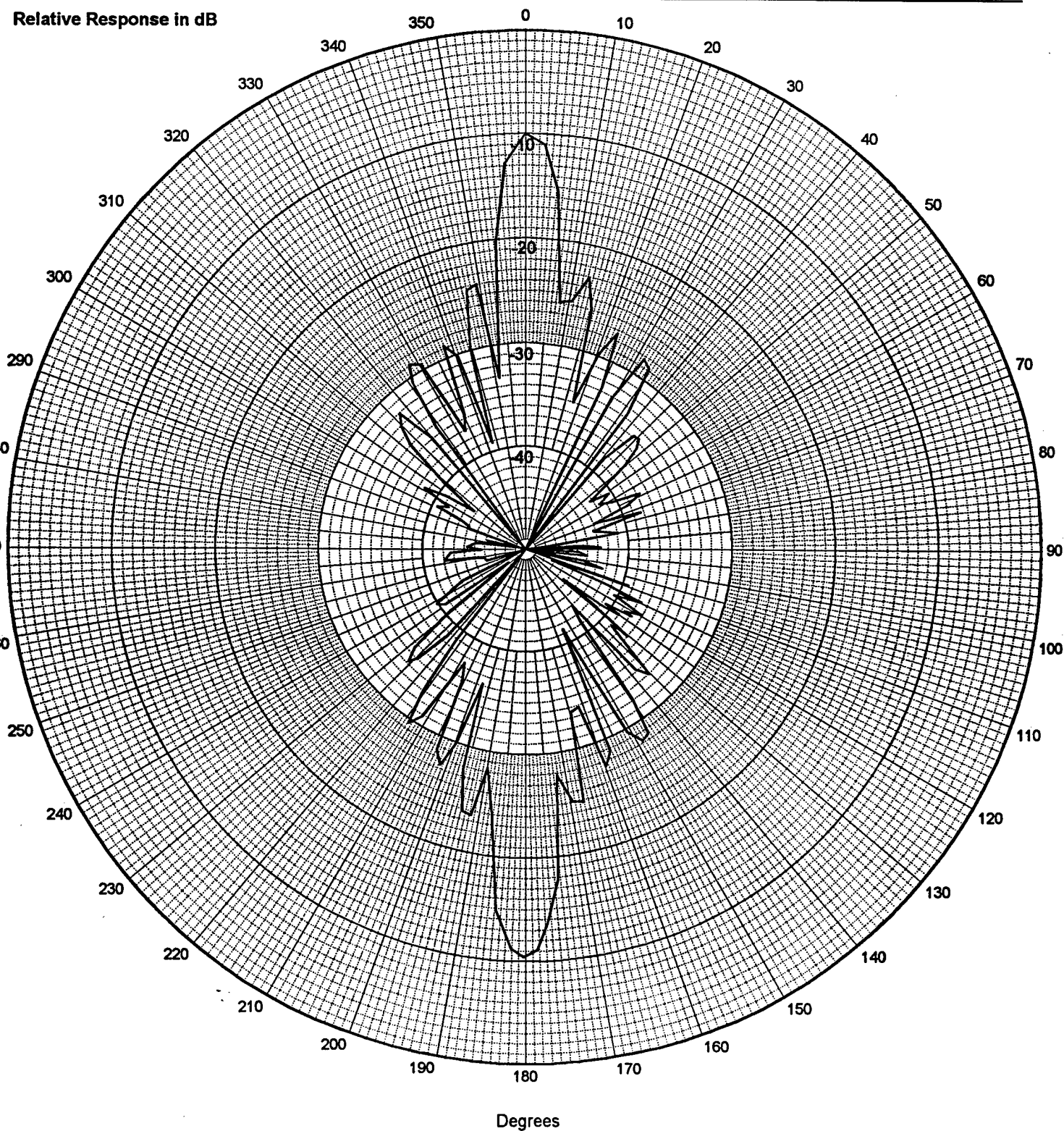
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UNDERWATER SOUND REFERENCE DETACHMENT  
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USRD NO. 0779-117  
ANECHOIC TANK FACILITY  
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 6895 kPa ( 703.1 m )  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB

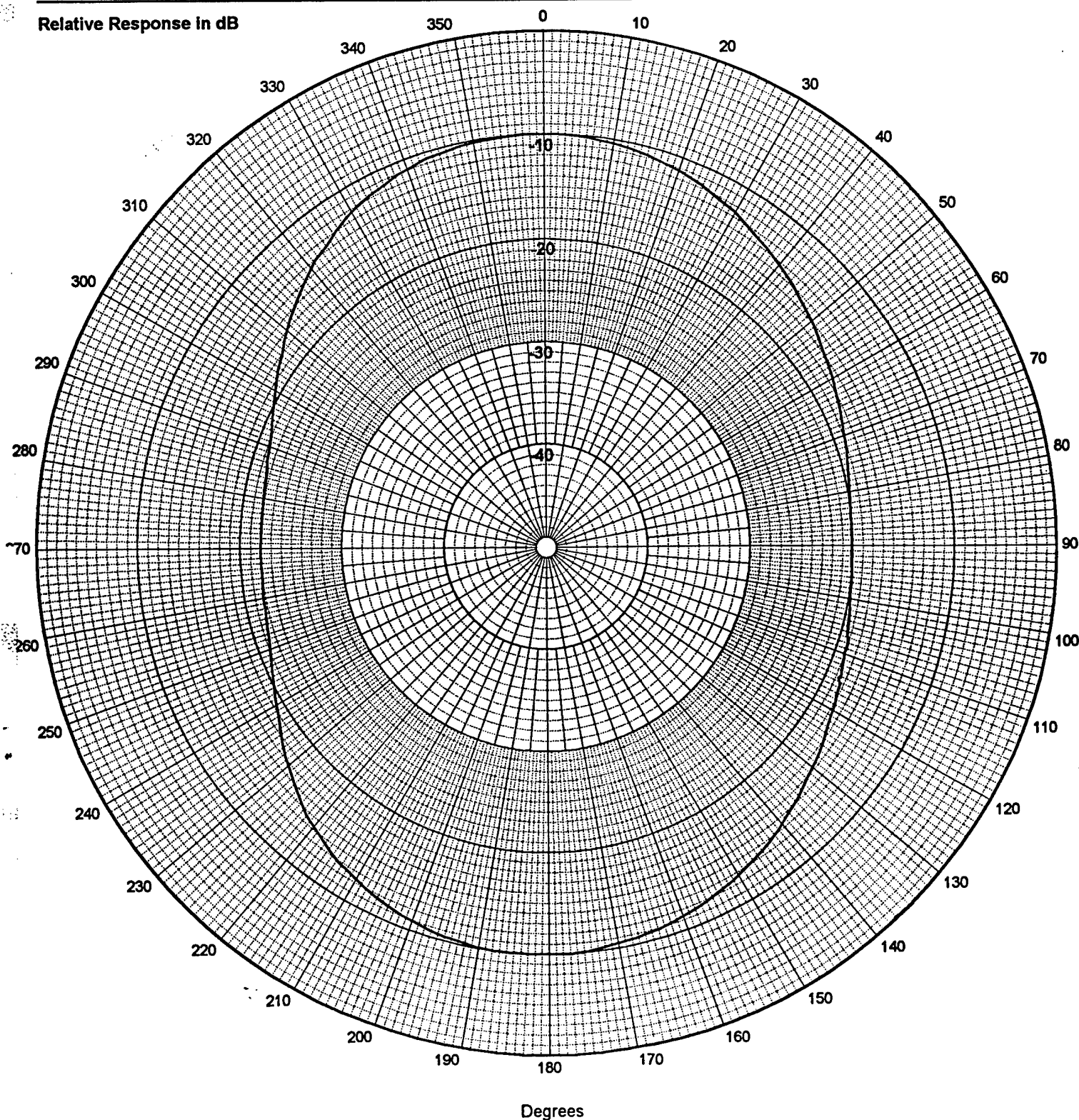




## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
10 kHz

Relative Response in dB

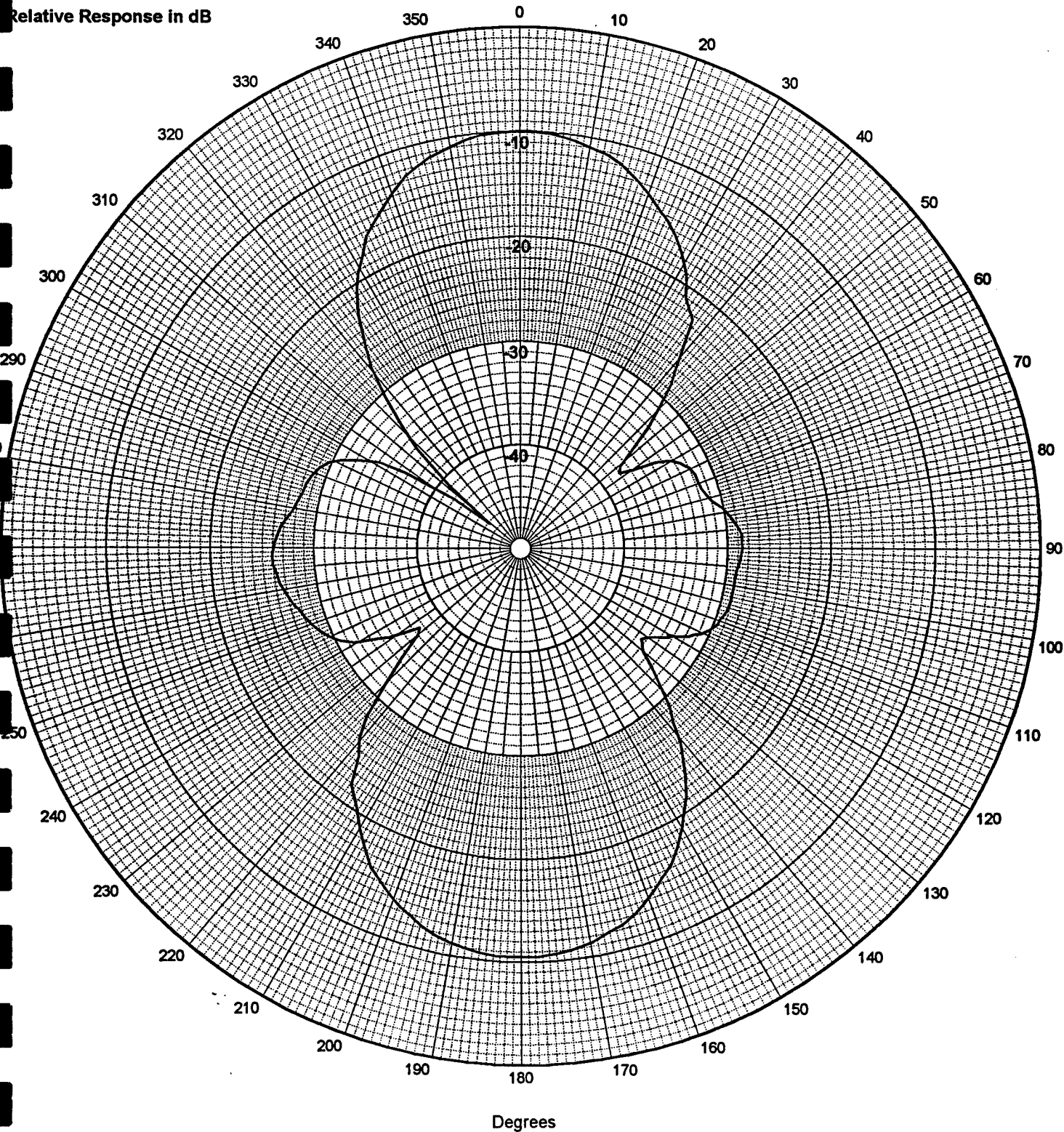


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## DIRECTIONAL RESPONSE

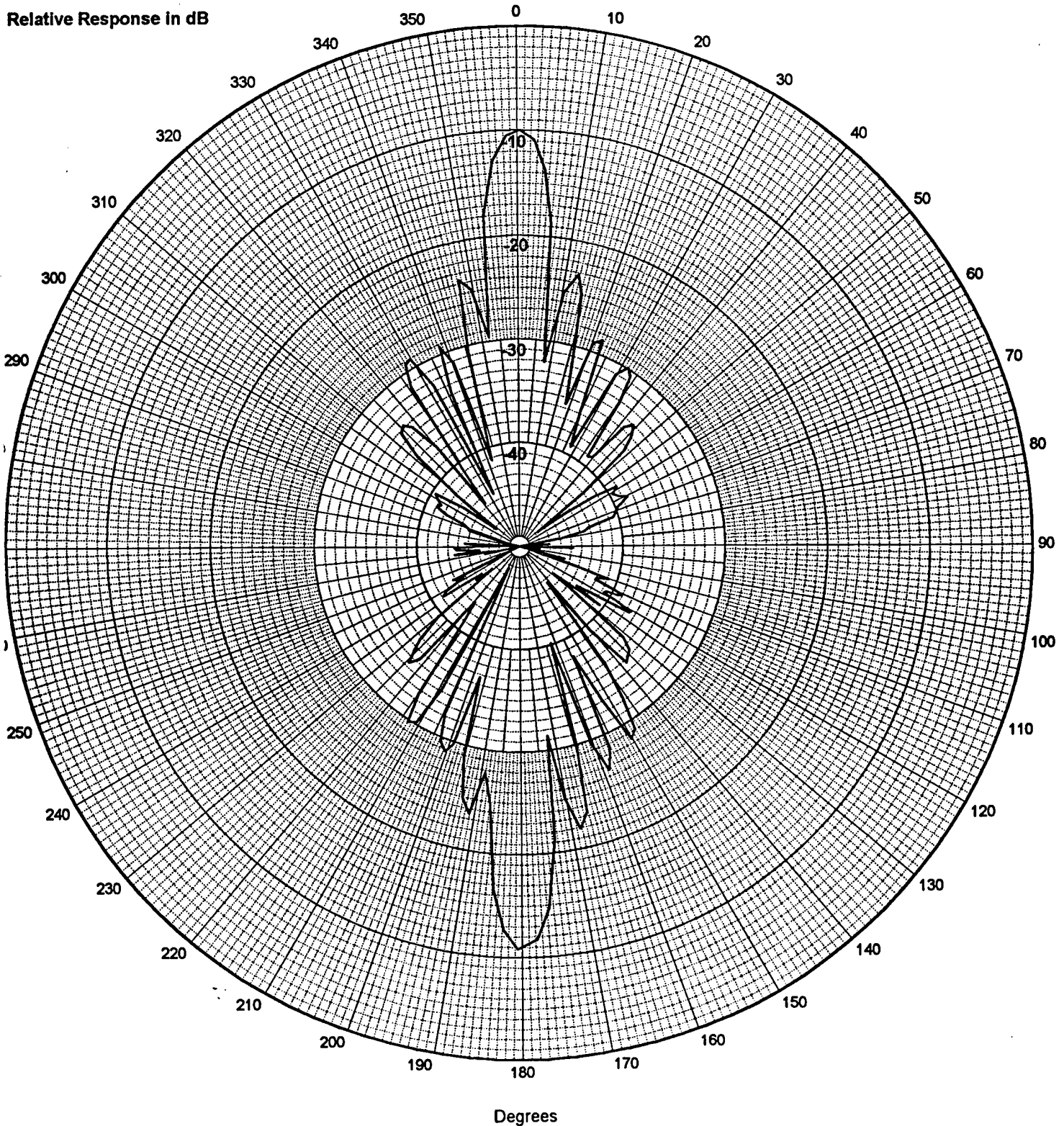
Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
Y Plane  
20 kHz



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4K-1  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure  
Water Temperature: 22° C  
Transmit  
XY Plane  
100 kHz

Relative Response in dB



A vertical dashed line runs down the left side of the page, consisting of a series of short, thick black horizontal bars separated by gaps.

# Appendix F





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ORLANDO FL 32856-8337

IN REPLY REFER TO:

3965  
Ser X72500-0851  
OCT 2 1996

USRD CALIBRATION MEMORANDUM NO. 0851

Subj: MEASUREMENTS ON PIEZOCOMPOSITE TRANSDUCERS SERIALS 4-44, 4-69,  
AND 10-54 THROUGH 10-57

Ref: (a) Fonecon, Mr. T. Howarth of NRL to Mr. R. Drake of NUWC-USRD, 23 Jul 1996  
(b) NUWC-USRD Job Order No. S72511

Encl: (1) USRD Charts 1 through 54 and Table 1  
(2) USRD Drawing 62785

1. Measurements on the subject transducers were made in the Lake Facility during the period 25 July through 23 August 1996 as arranged in reference (a). Mr. T. Howarth of the Naval Research Laboratory, Washington, DC was present to specify and assist with the measurements. Funds for this service were provided by reference (b).

2. Free-field voltage sensitivity (FFVS), transmitting current response (TCR), transmitting voltage response (TVR), pressure waveform (PW), and directional response (DR) in the horizontal (XY) plane were measured in the frequency range 1.0 to 300 kHz, at the water temperature 30°C, and at a depth of 3.9 m (38 kPa). Conditions and results of the measurements are presented in enclosure (1).

3. Serials 4-44 and 4-69 were measured prior to shock and again after shock. Charts 4 and 13 depict the pressure waveform that these serials were exposed to.

Further dissemination only as directed by  
Commanding Officer, Naval Research  
Laboratory ( OCT 2 1996 ) or  
higher DoD authority.

3965  
Ser X72500-0851  
OCT 2 1996

USRD CALIBRATION MEMORANDUM NO. 0851

4. Orientation was as described for a plane in enclosure (2). An arrow drawn on the transducer's face was pointing in the +Z direction.

  
D. M. MCGRATH  
Project Leader

  
R. M. DRAKE  
Head, Acoustic Measurements T&E Branch

Copy to:  
NRL (Code 7135, T. Howarth)(5)  
NUWC-USRD (Code 251, R. Ting)  
(Code 2572, K. Benjamin)  
(Code 2582)

TABLE 1  
DATA DIRECTORY  
Piezocomposite Transducers

	CHART
<b>Serial 4-44</b>	
FFVS .....	1
TCR .....	2
TVR .....	3
PW .....	4
DR .....	5-9
<b>Serial 4-69</b>	
FFVS .....	10
TCR .....	11
TVR .....	12
PW .....	13
DR .....	14-18
<b>Serial 10-54</b>	
FFVS .....	19
TVR .....	20
DR .....	21-27
<b>Serial 10-55</b>	
FFVS .....	28
TVR .....	29
DR .....	30-36
<b>Serial 10-56</b>	
FFVS .....	37
TVR .....	38
DR .....	39-45
<b>Serial 10-57</b>	
FFVS .....	46
TVR .....	47
DR .....	48-54

## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 4-44

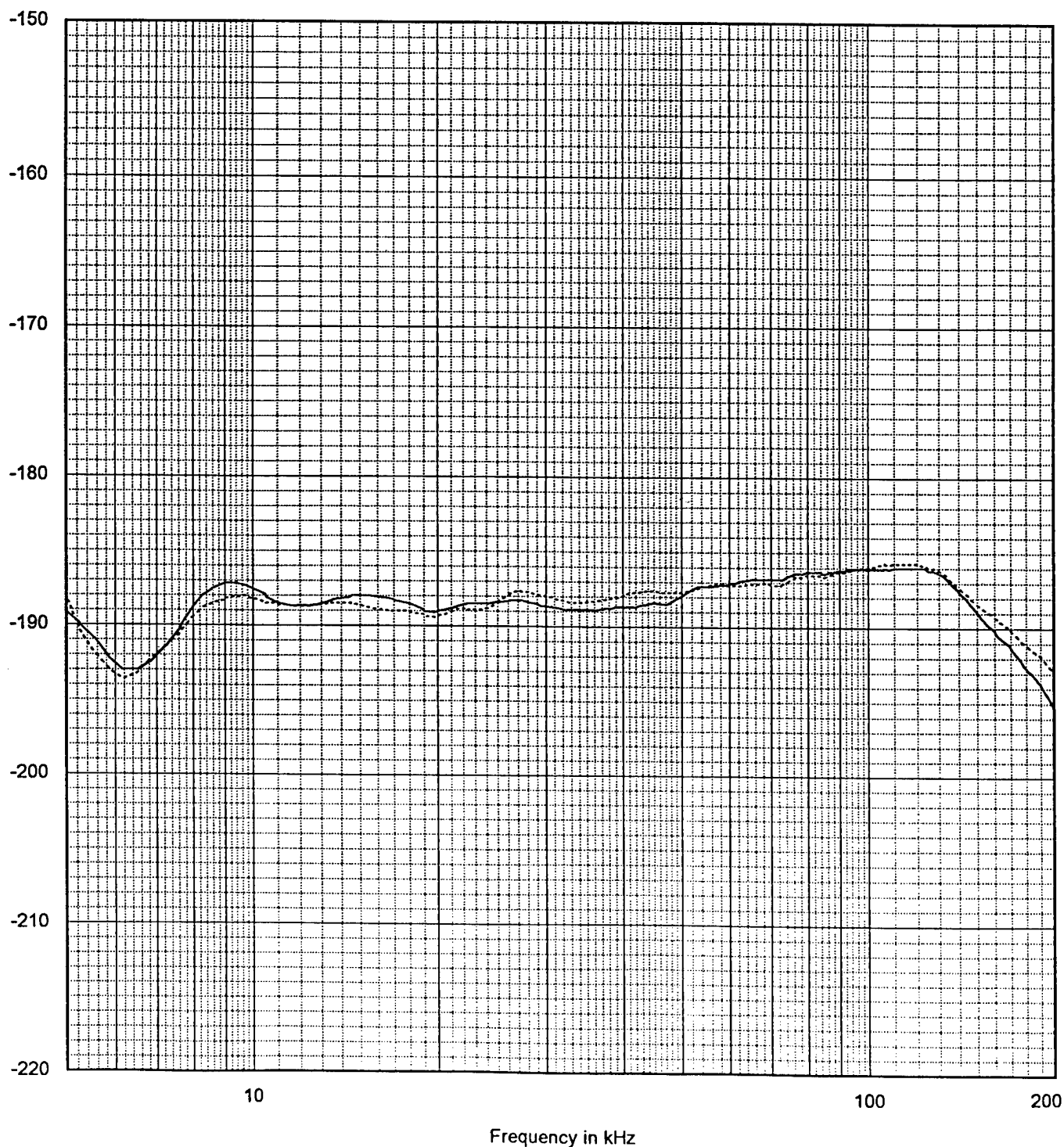
Open-circuit voltage measured at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)

8.9 nF Capacitance measured at end of 15.0-m cable

— Pre-Shock  
- - - Post-Shock





## TRANSMITTING CURRENT RESPONSE

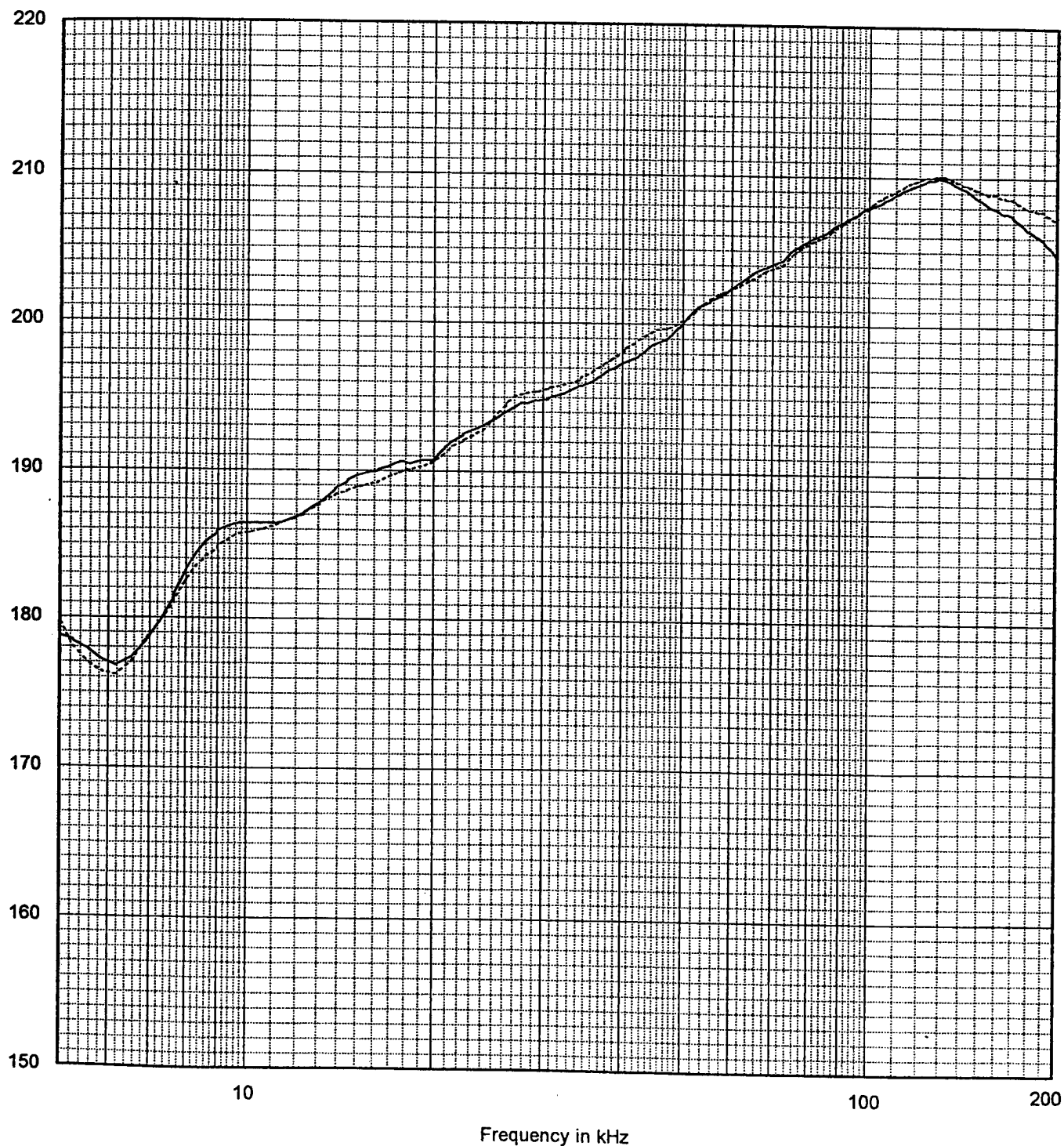
Piezocomposite Transducer Serial 4-44

Pressure at one meter per ampere measured at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)

— Pre-Shock  
- - - Post-Shock



## TRANSMITTING VOLTAGE RESPONSE

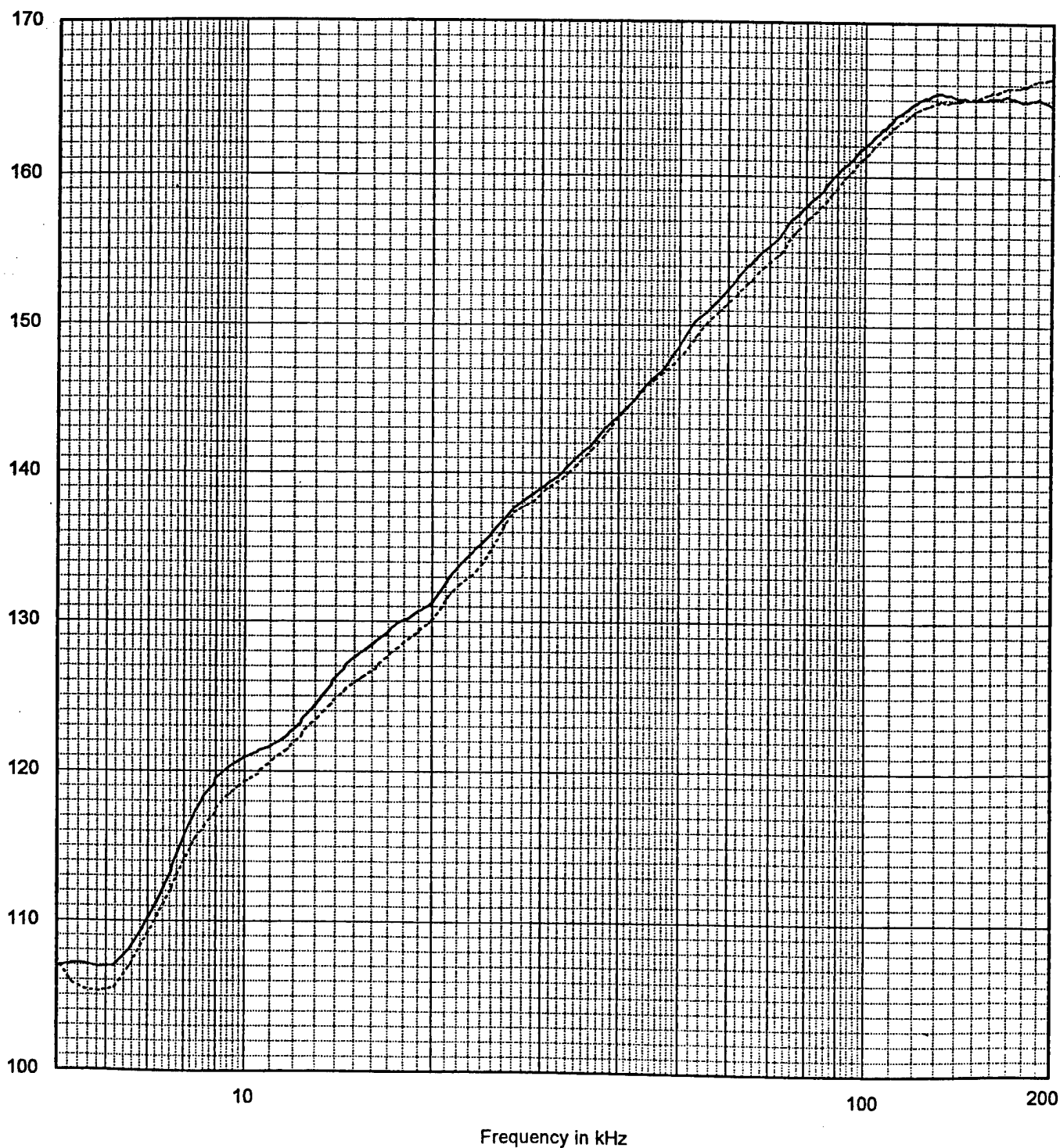
Piezocomposite Transducer Serial 4-44

Pressure at one meter per volt applied at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)

— Pre-Shock  
- - - Post-Shock

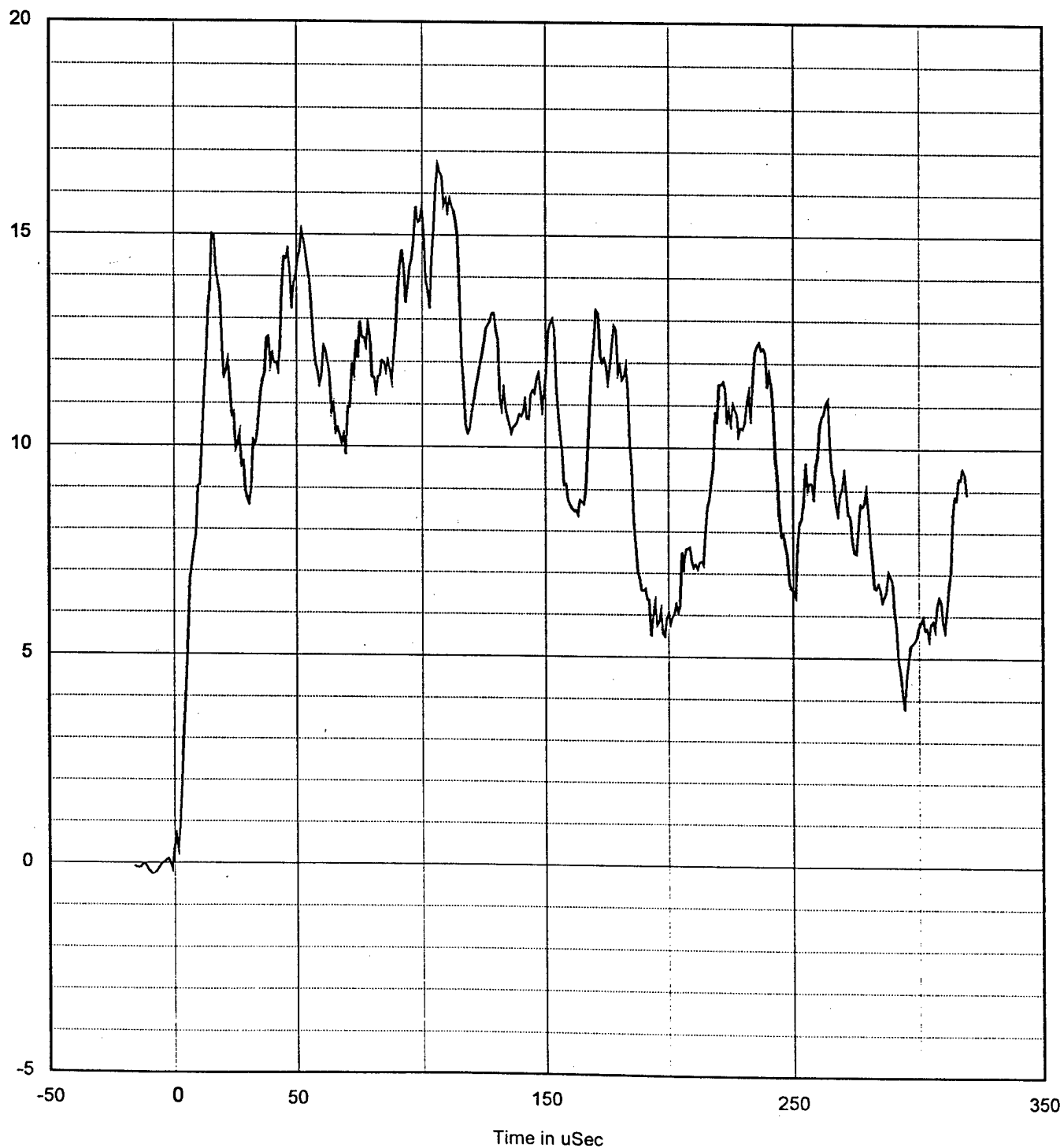


## PRESSURE WAVEFORM

Piezocomposite Transducer Serial 4-44

Pressure measured in front of sample in Conical Shock Tube

Comparable to shot #4 of the Heavyweight Shock Test of MIL-S-901D



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 44

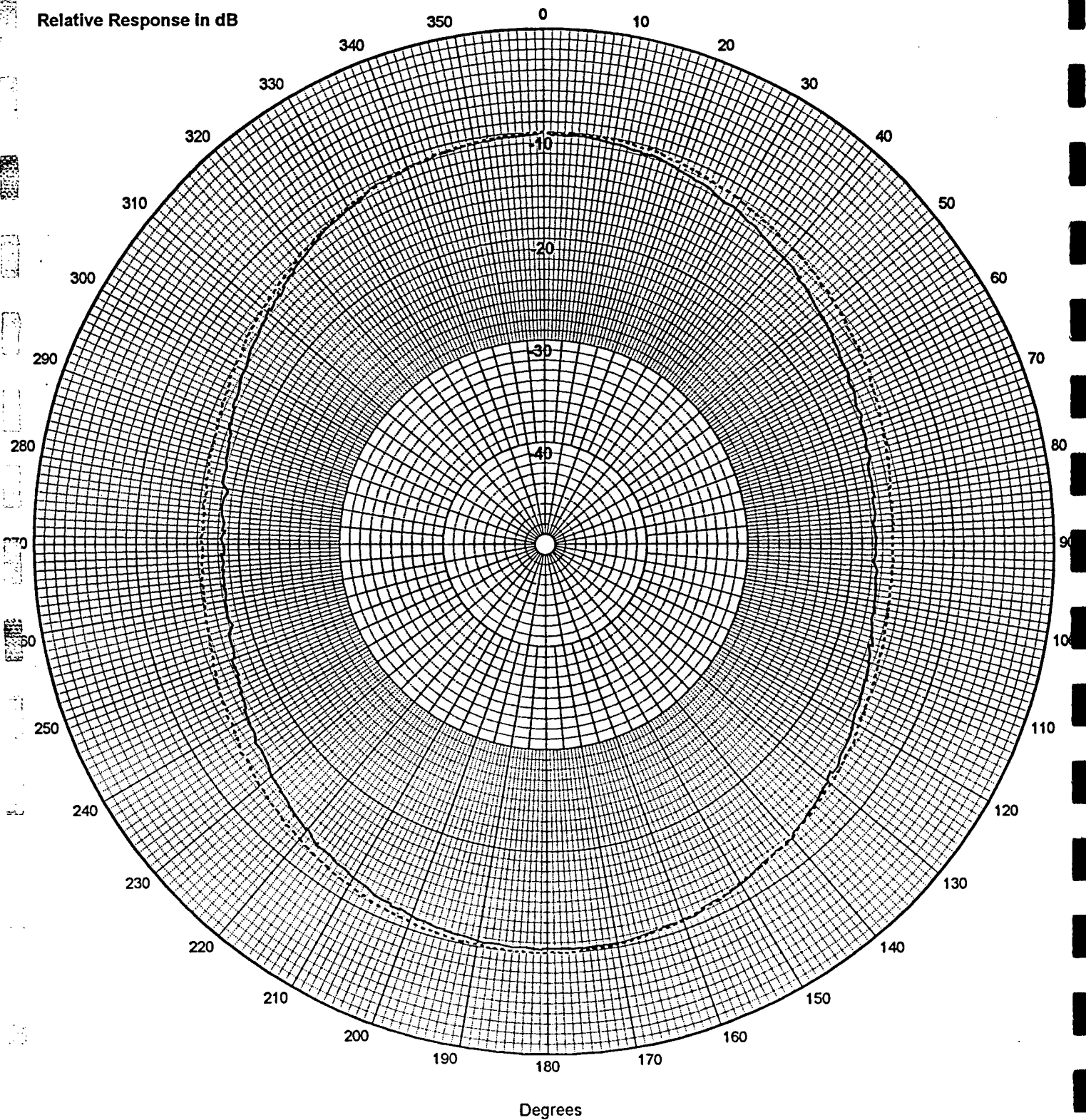
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 10 kHz

— Pre-Shock  
- - - Post-Shock

Relative Response in dB





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AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 44

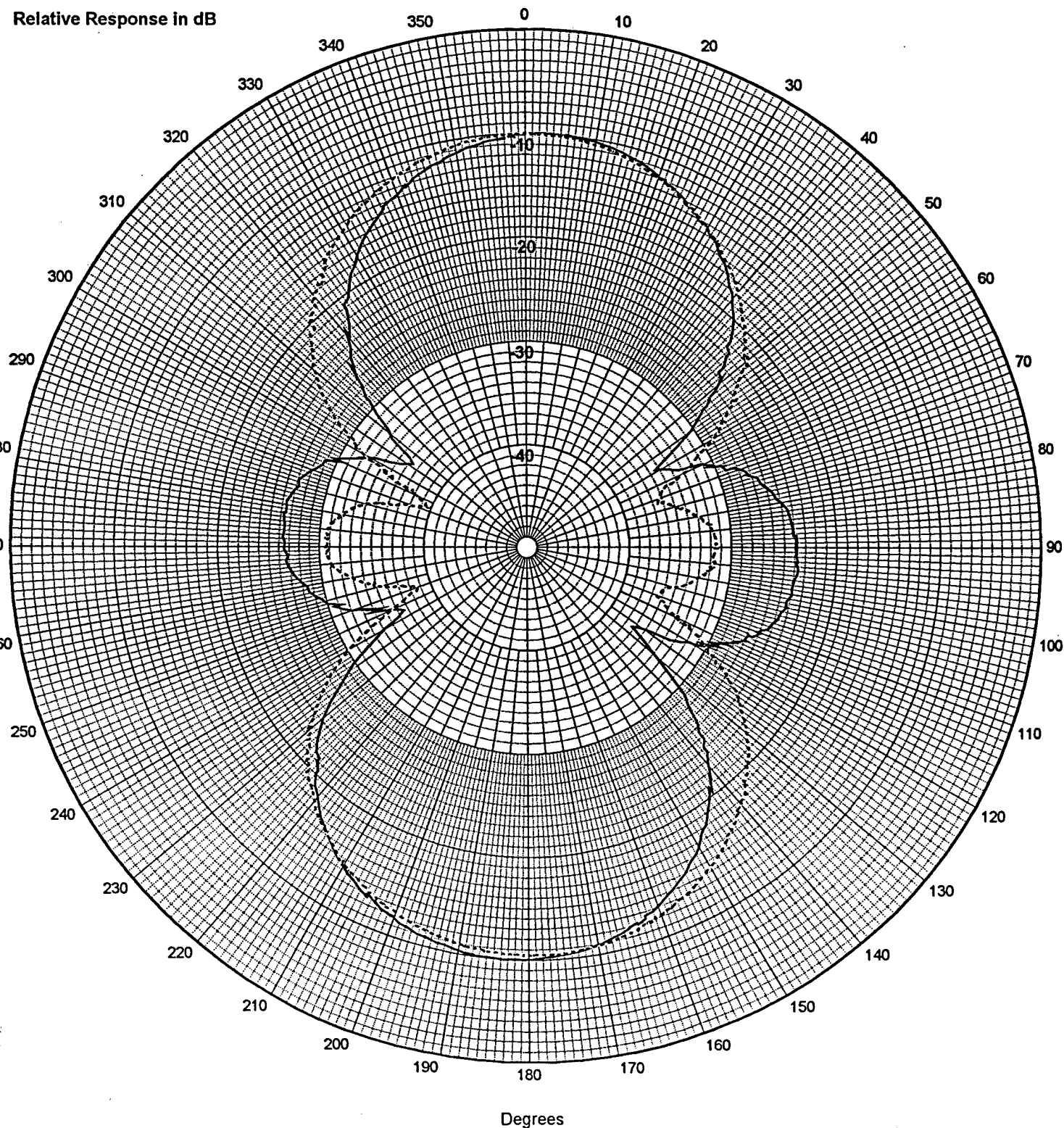
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 20 kHz

—— Pre-Shock  
----- Post-Shock

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 44

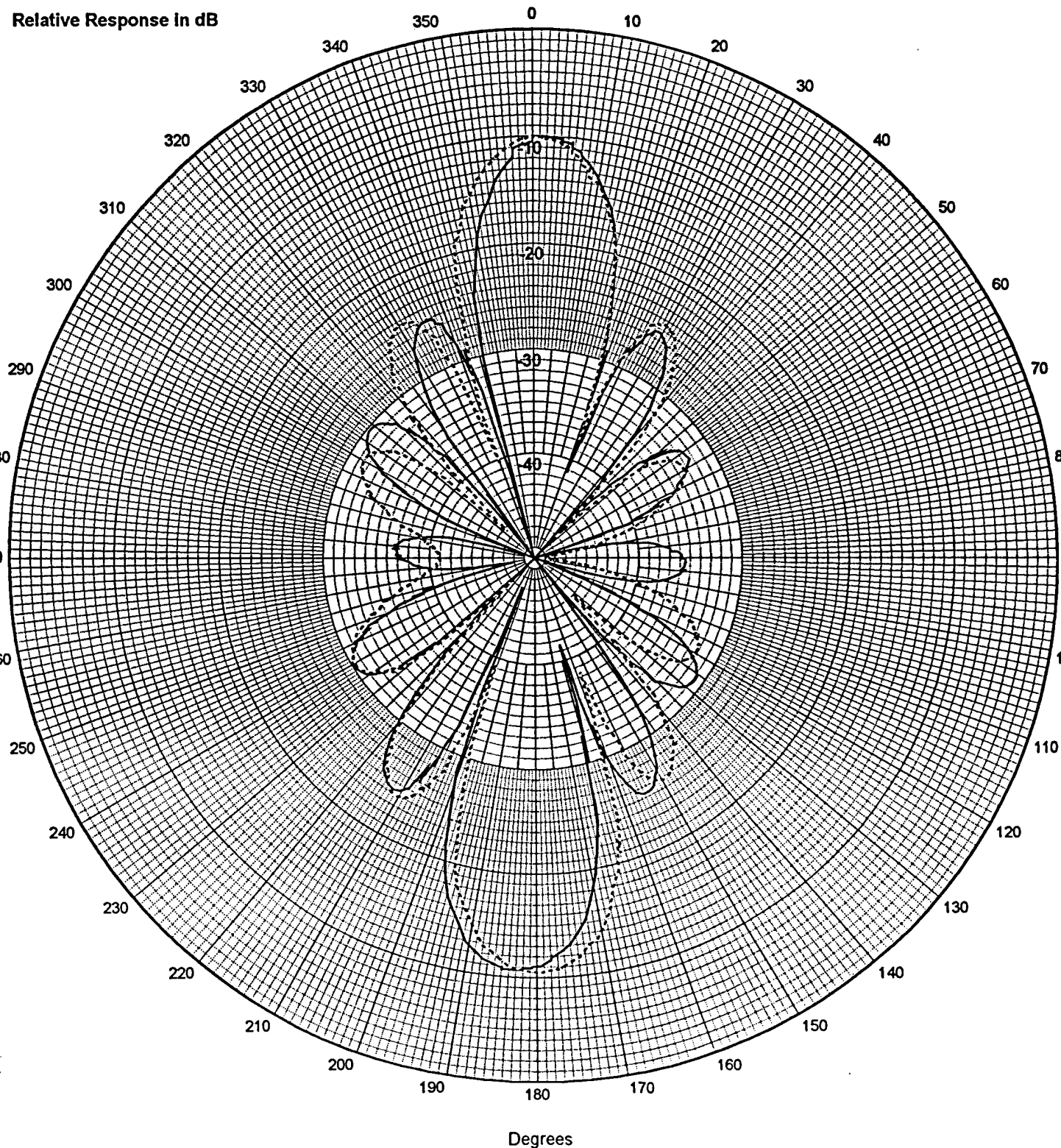
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 50 kHz

— Pre-Shock  
- - - Post-Shock

Relative Response in dB



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USRD NO: 0851-8  
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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 44

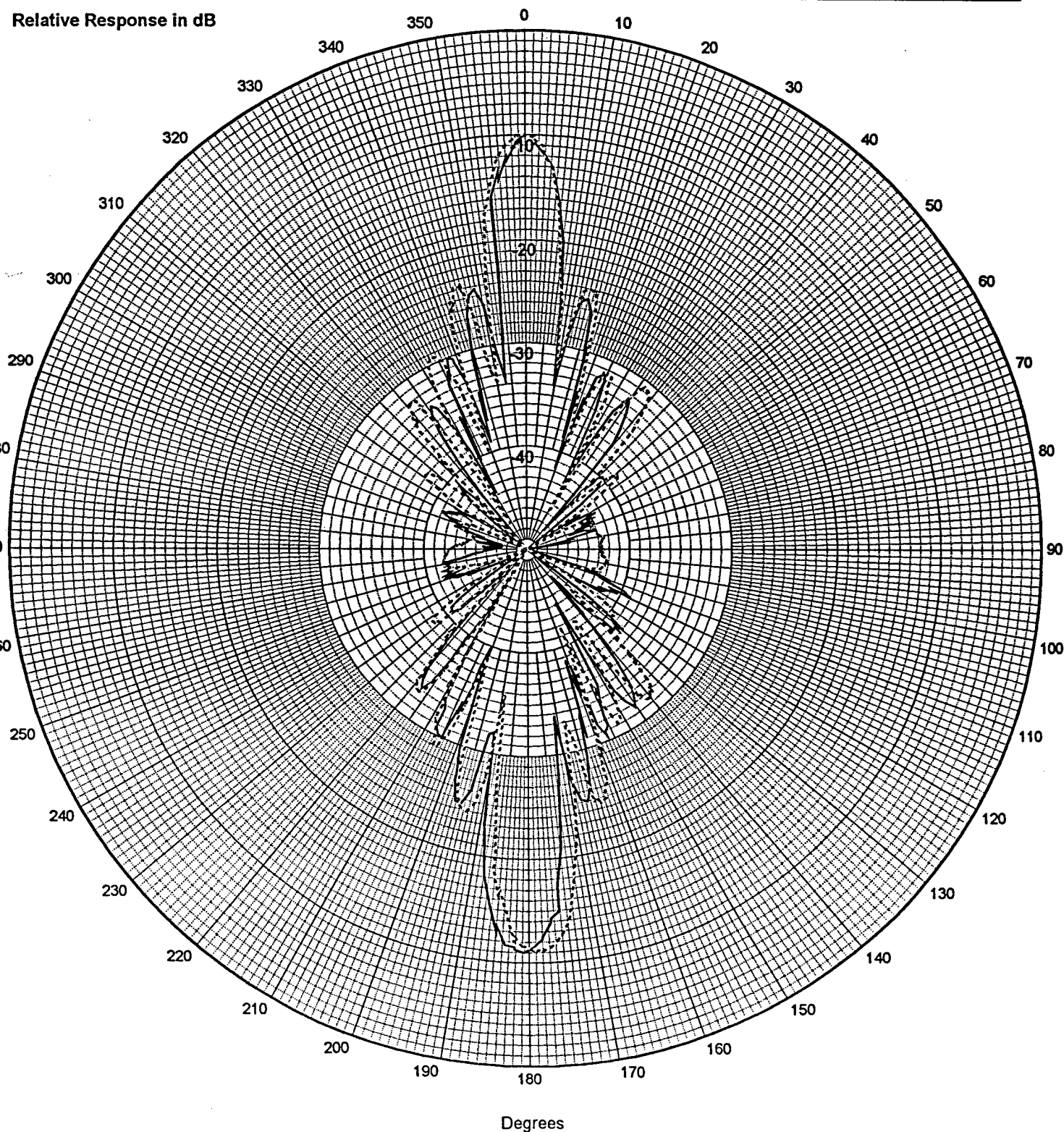
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 100 kHz

— Pre-Shock  
- - - Post-Shock

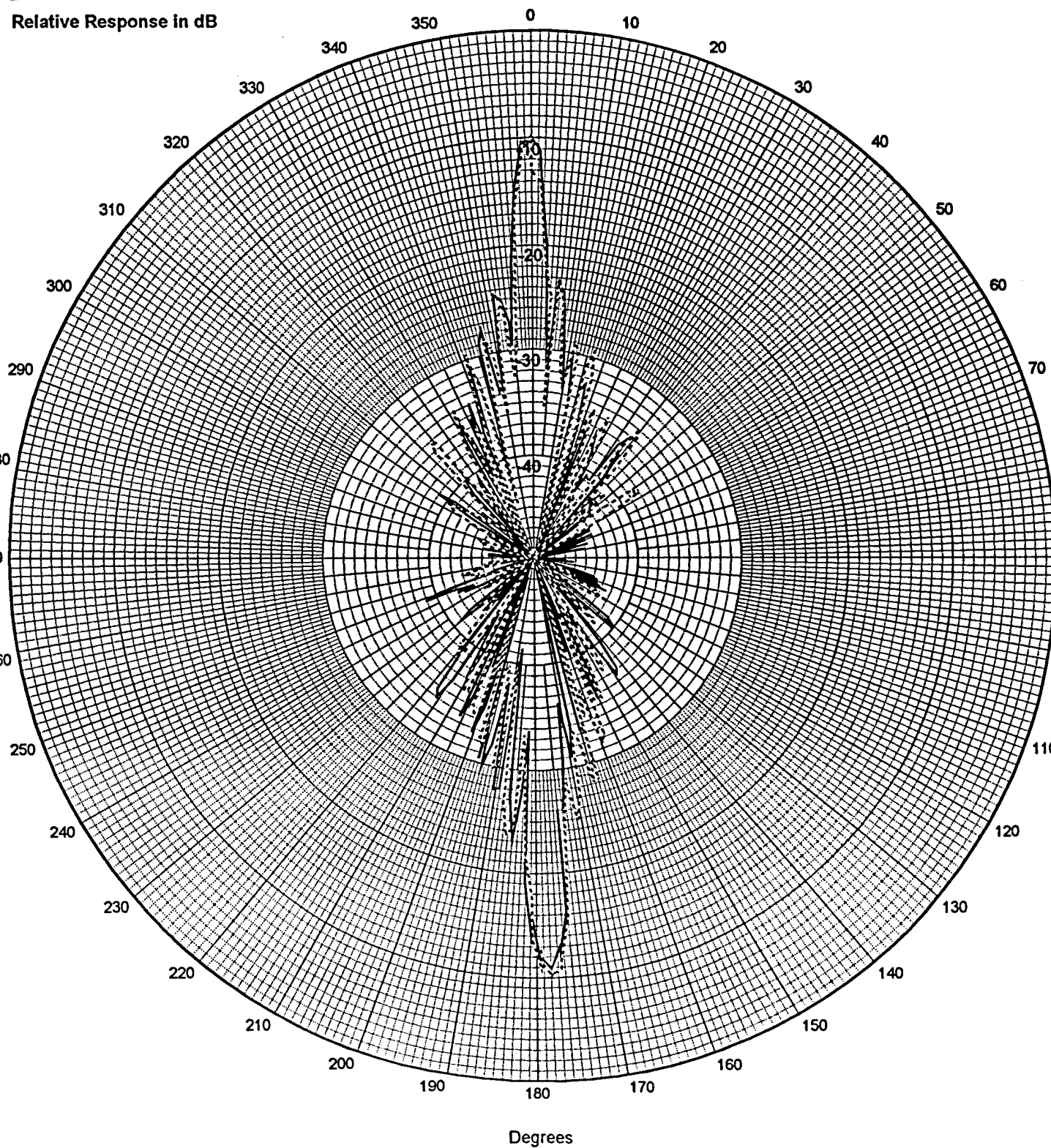
Relative Response in dB



USRD NO: 0851-9  
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Receive, XY Plane, 200 kHz

\_\_\_\_\_ Pre-Shock  
 ..... Post-Shock





## FREE-FIELD VOLTAGE SENSITIVITY

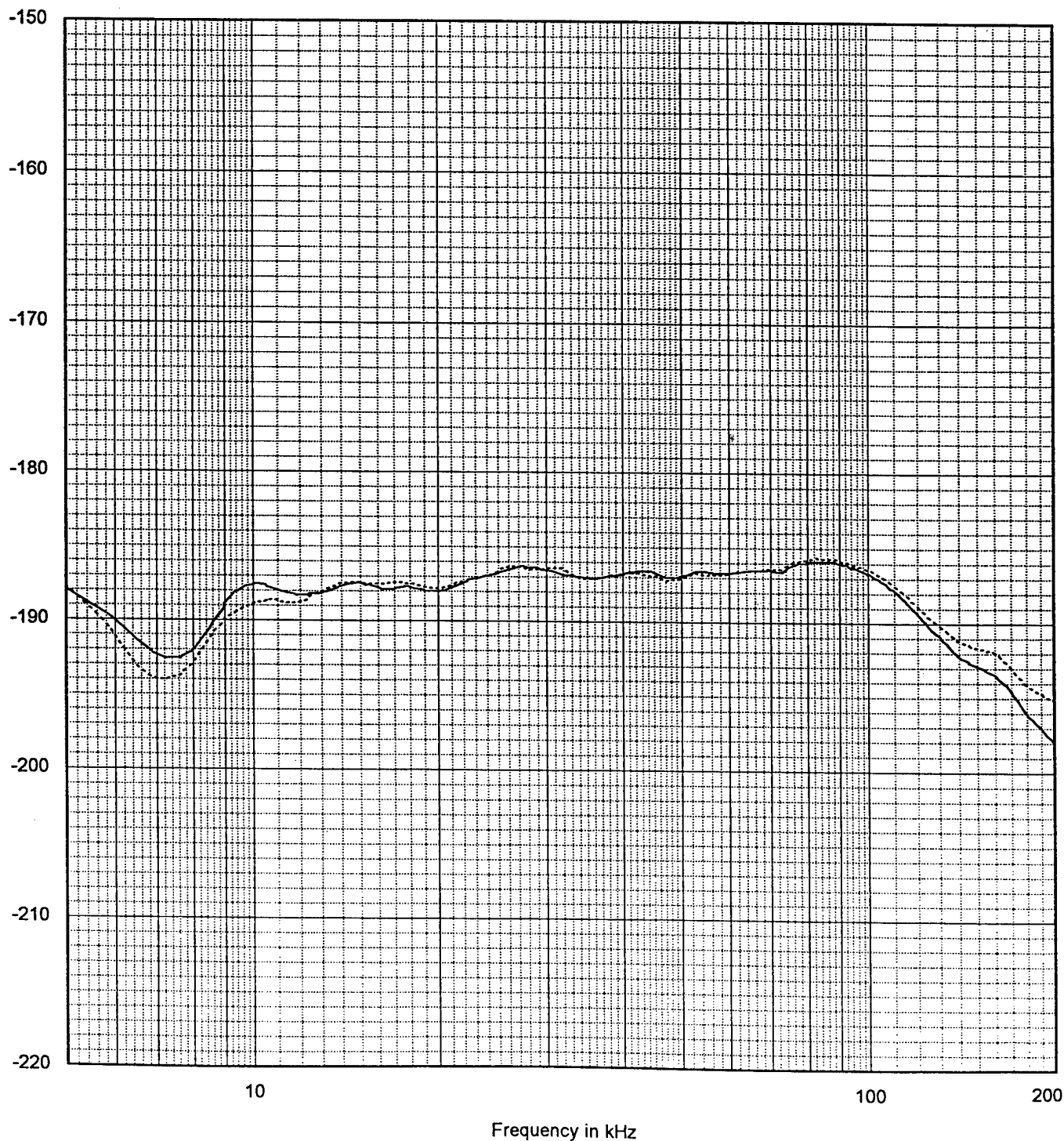
Piezocomposite Transducer Serial 4-69

Open-circuit voltage measured at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)

— Pre-Shock  
- - - Post-Shock



## TRANSMITTING CURRENT RESPONSE

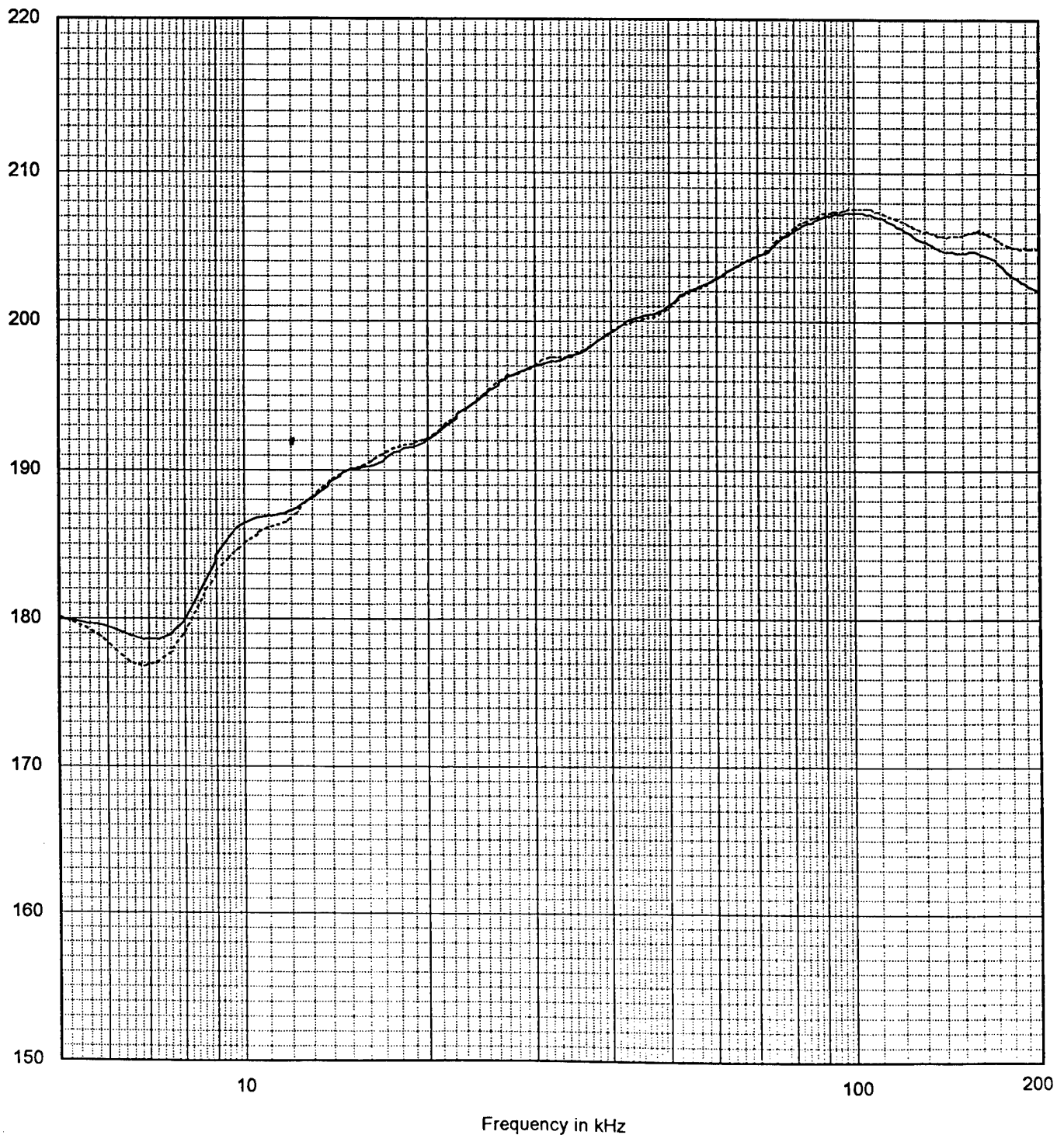
Piezocomposite Transducer Serial 4-69

Pressure at one meter per ampere measured at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)

——— Pre-Shock  
- - - - - Post-Shock



## TRANSMITTING VOLTAGE RESPONSE

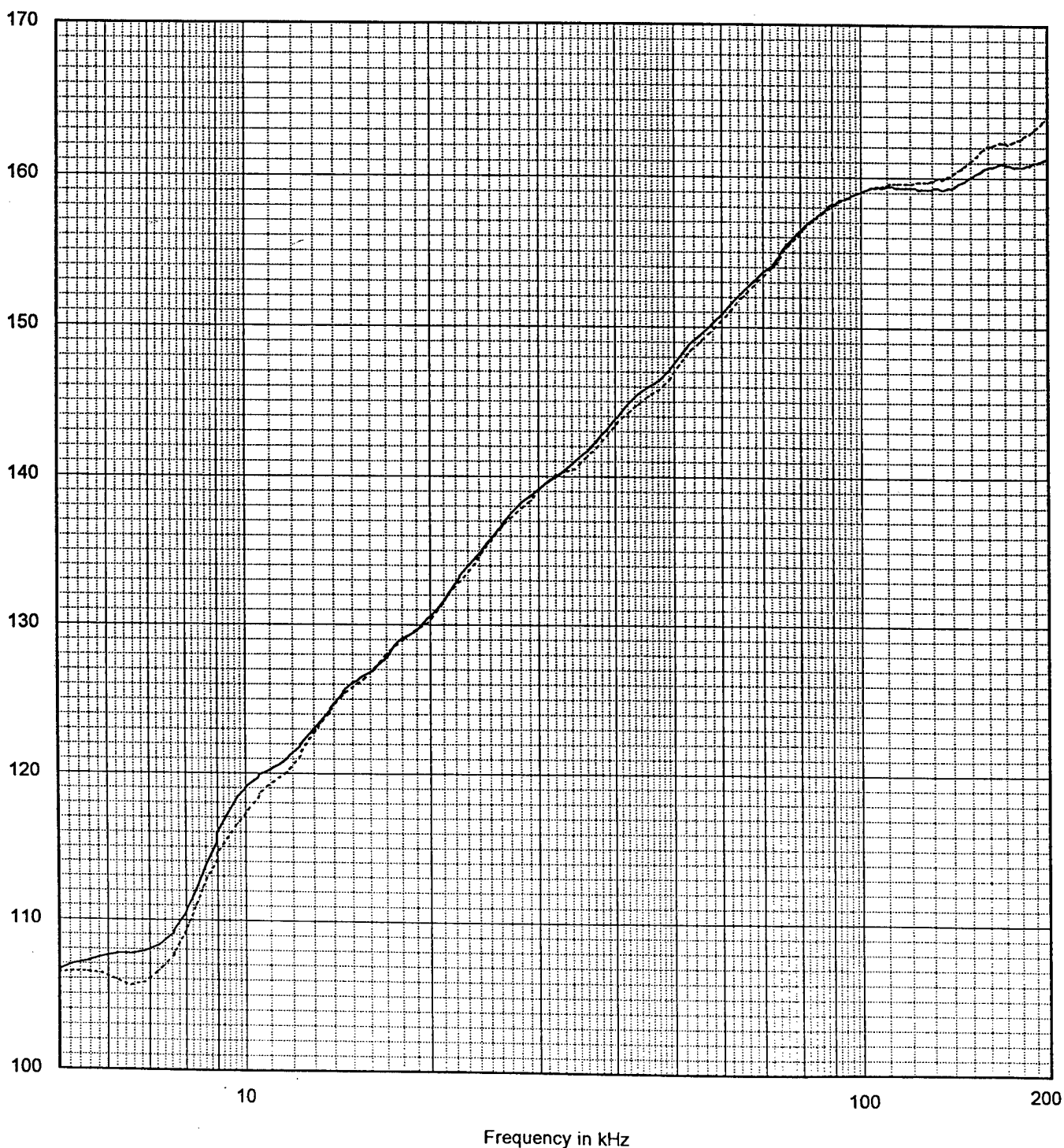
Piezocomposite Transducer Serial 4-69

Pressure at one meter per volt applied at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)

— Pre-Shock  
- - - Post-Shock

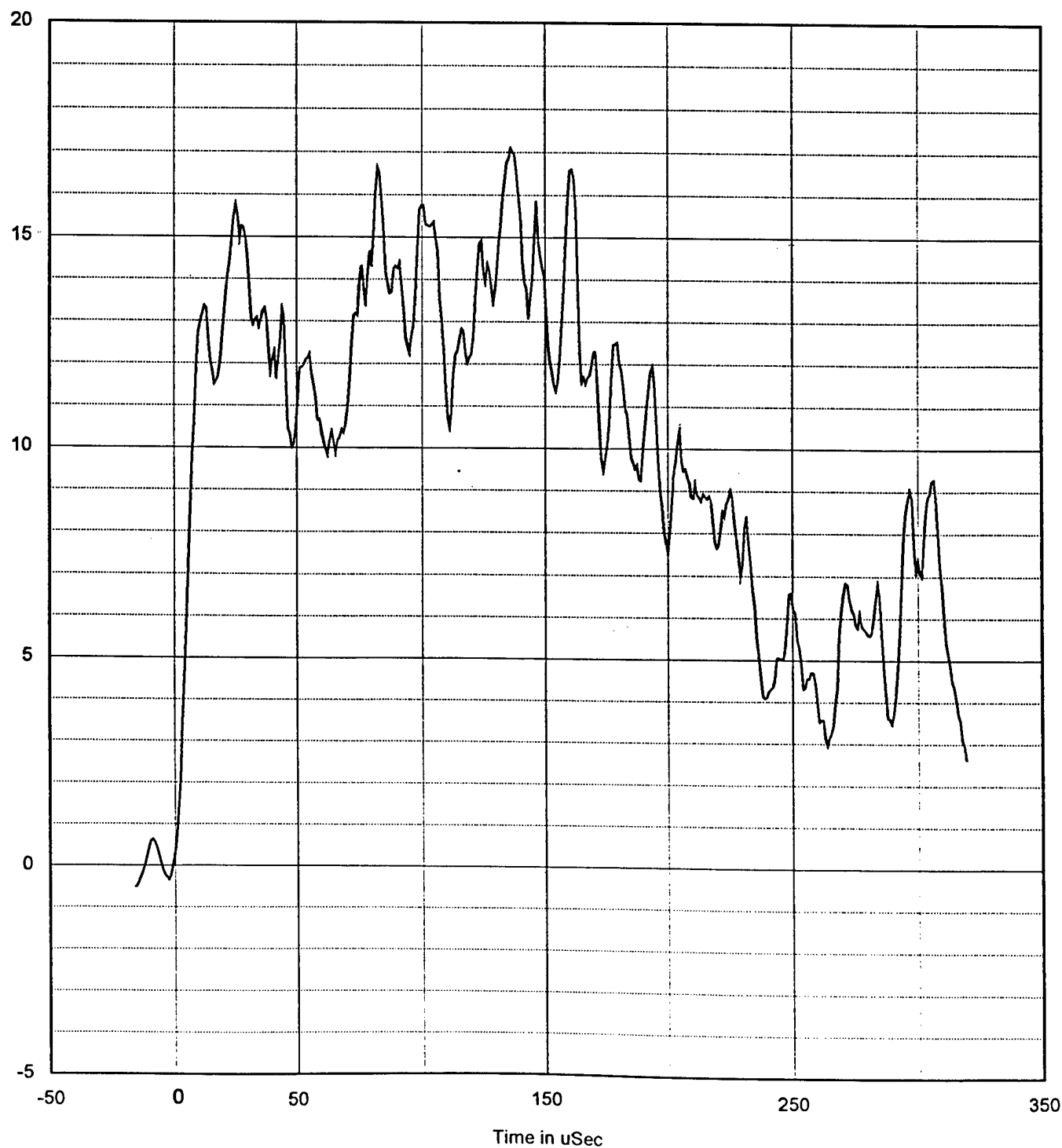


## PRESSURE WAVEFORM

Piezocomposite Transducer Serial 4-69

Pressure measured in front of sample in Conical Shock Tube

Comparable to shot #4 of the Heavyweight Shock Test of MIL-S-901D





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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 69

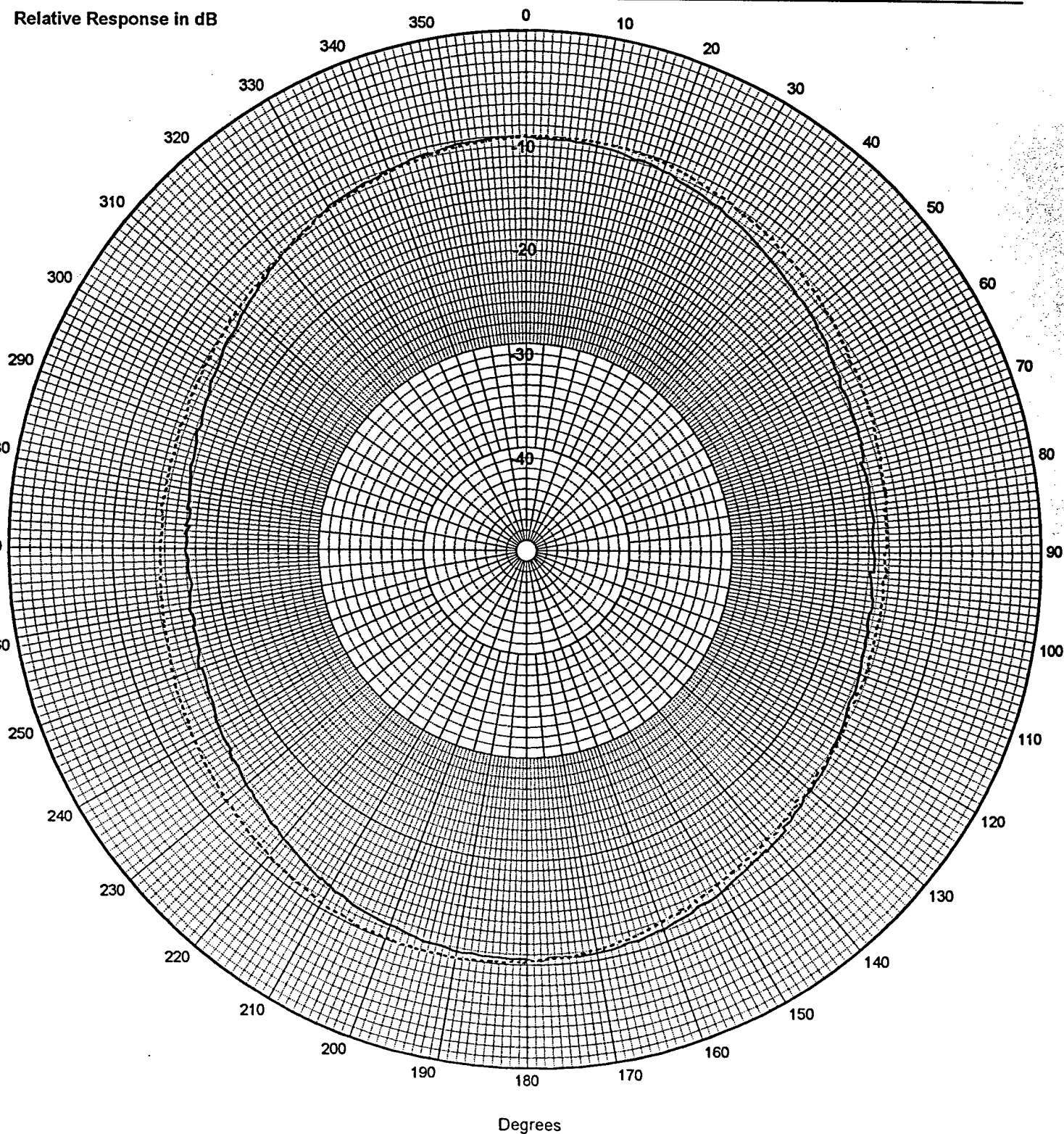
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 10 kHz

—— Pre-Shock  
----- Post-Shock

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 69

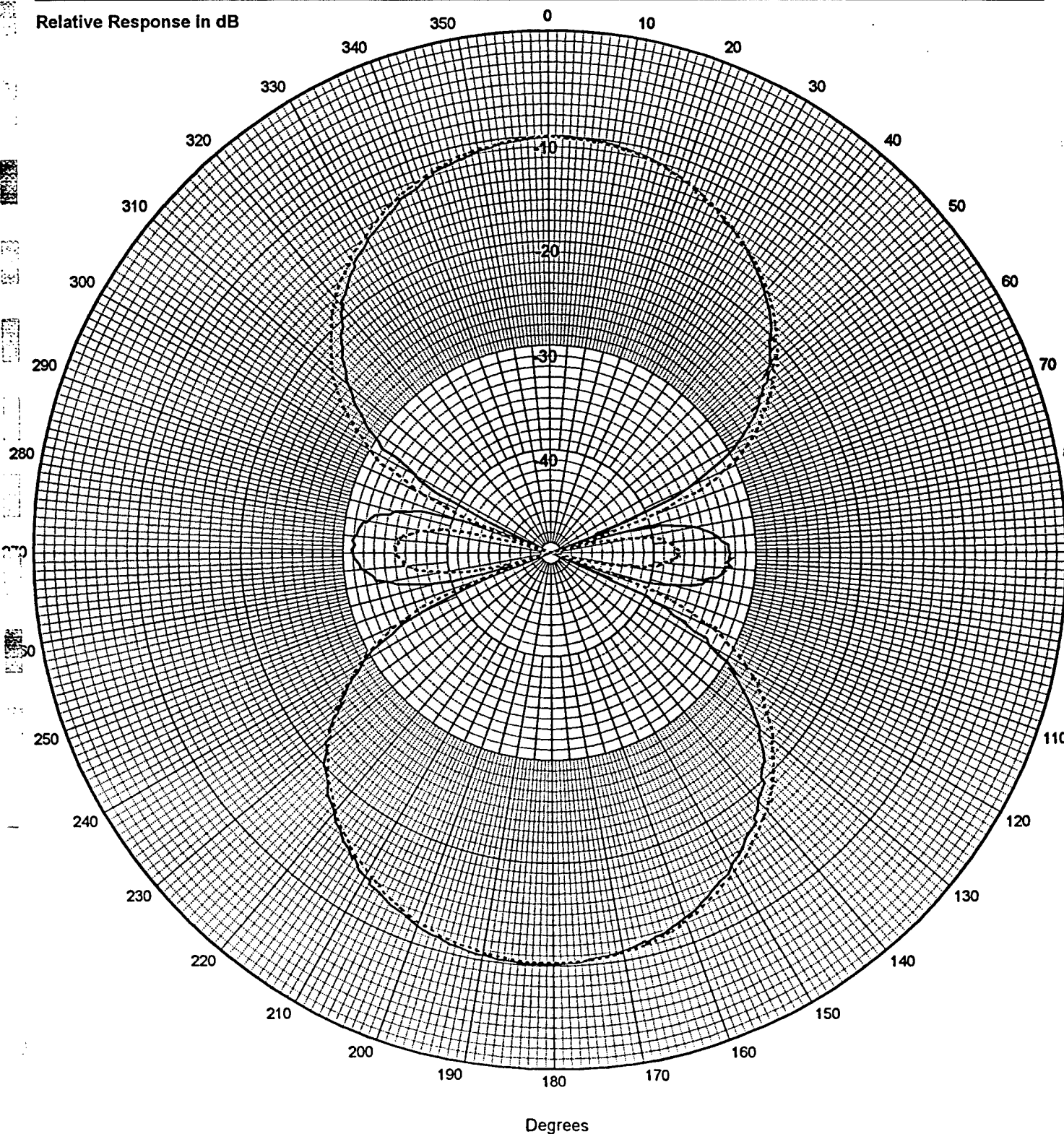
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 20 kHz

—— Pre-Shock  
----- Post-Shock

Relative Response in dB



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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 69

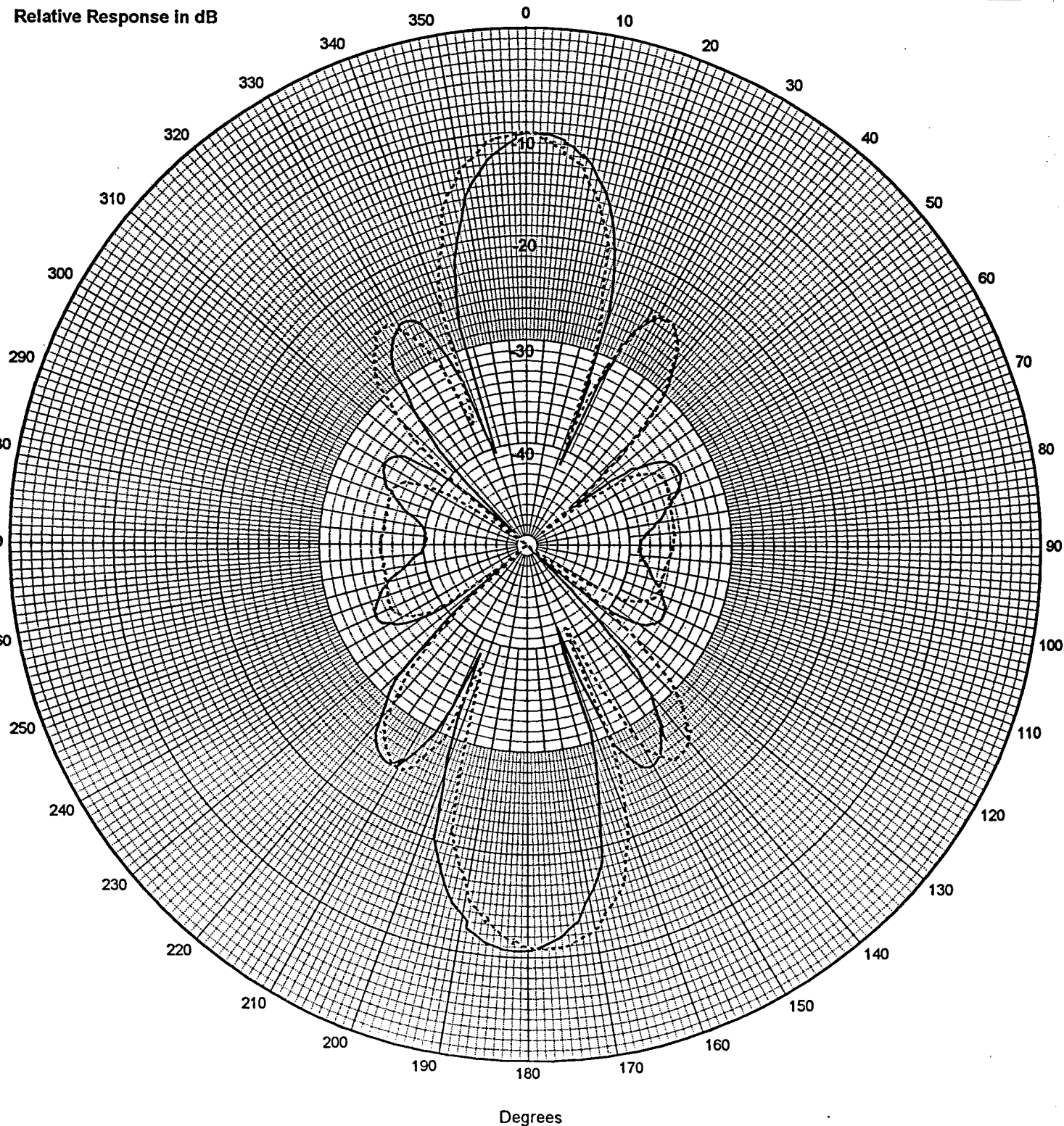
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 50 kHz

— Pre-Shock  
- - - Post-Shock

Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 69

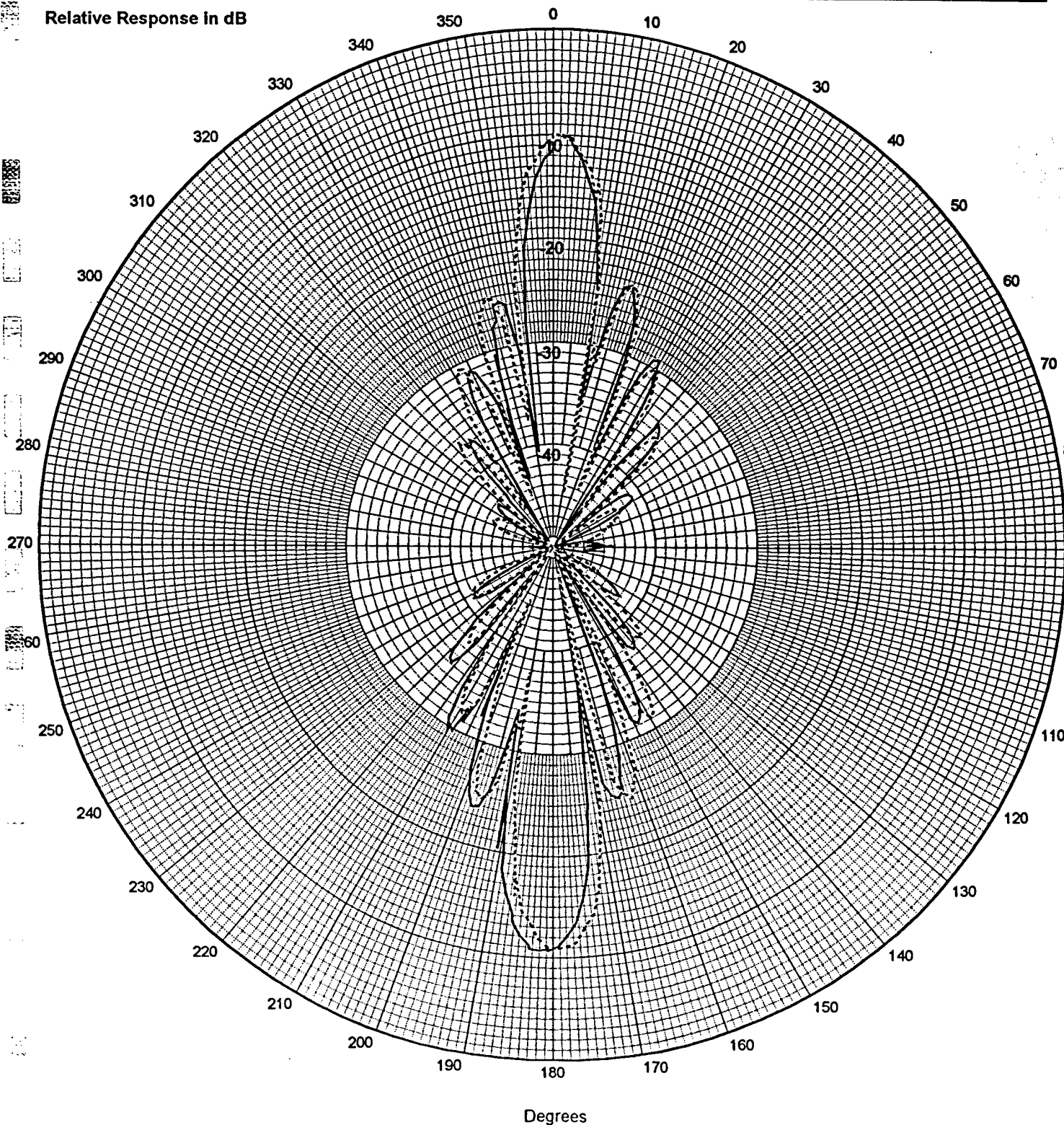
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 100 kHz

—— Pre-Shock  
- - - - - Post-Shock

Relative Response in dB





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## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 4 - 69

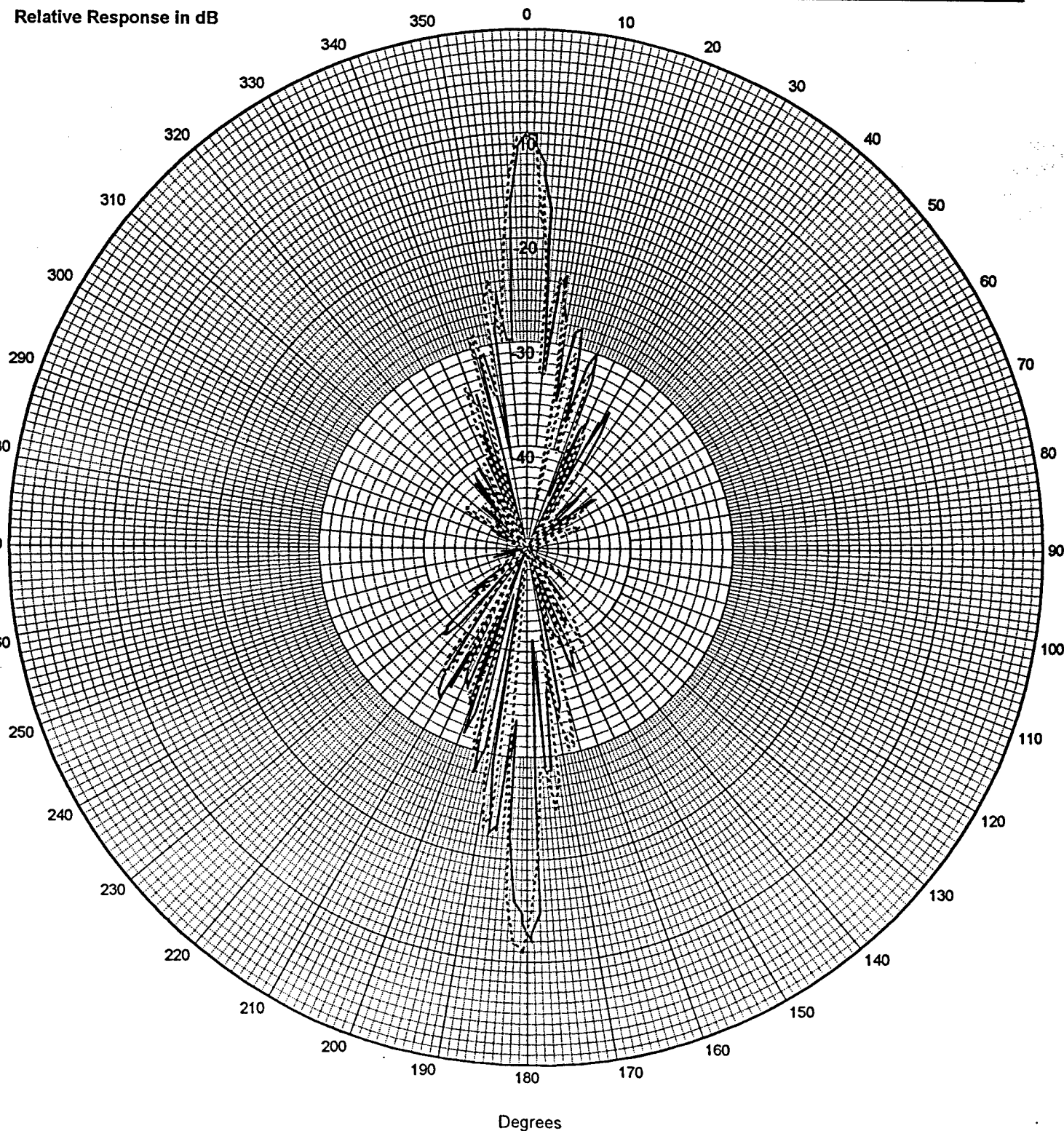
Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 200 kHz

—— Pre-Shock  
----- Post-Shock

Relative Response in dB



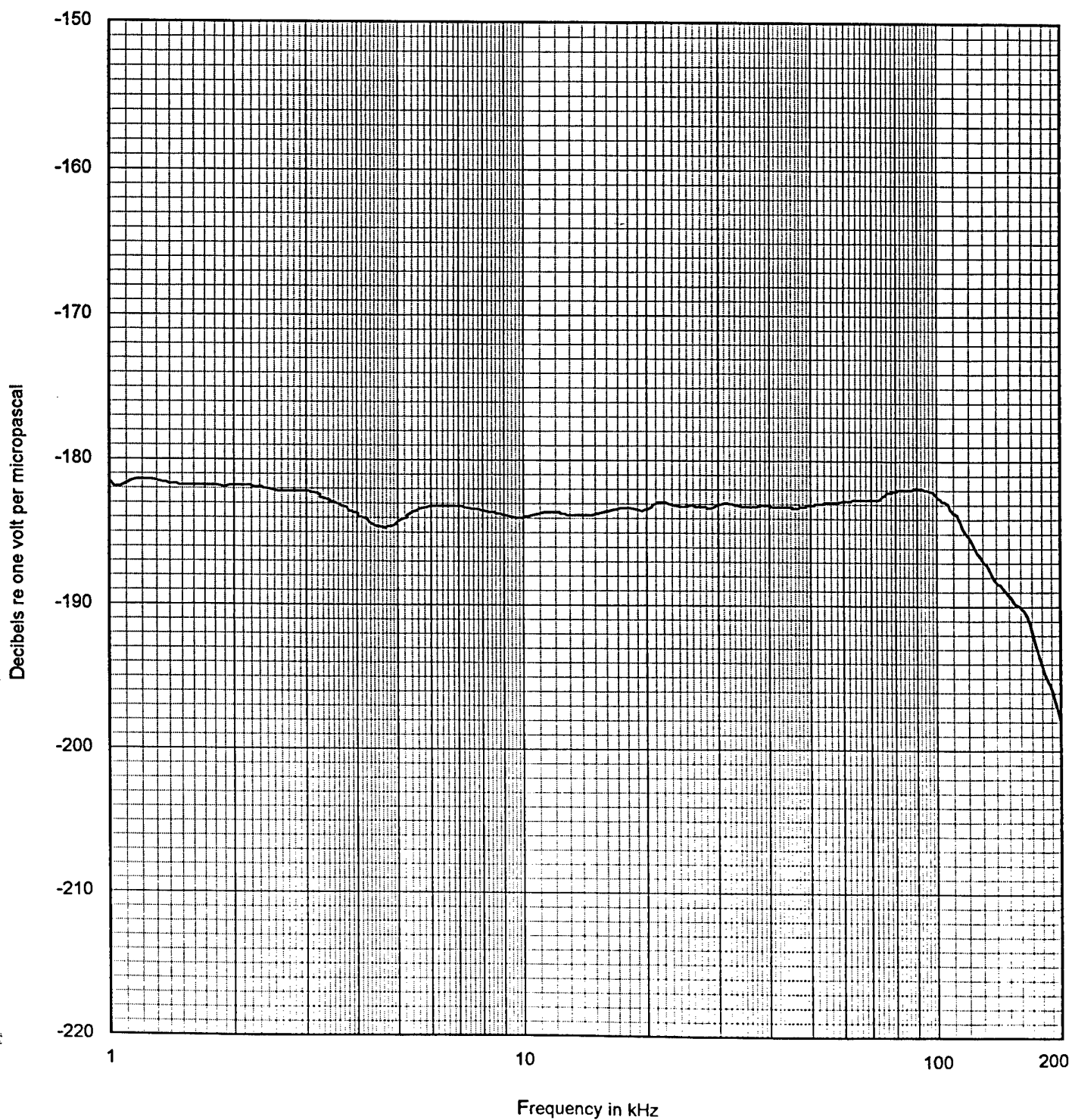
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 10-54

Open-circuit voltage measured at end of 15.0 -m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 ( 38 kPa )



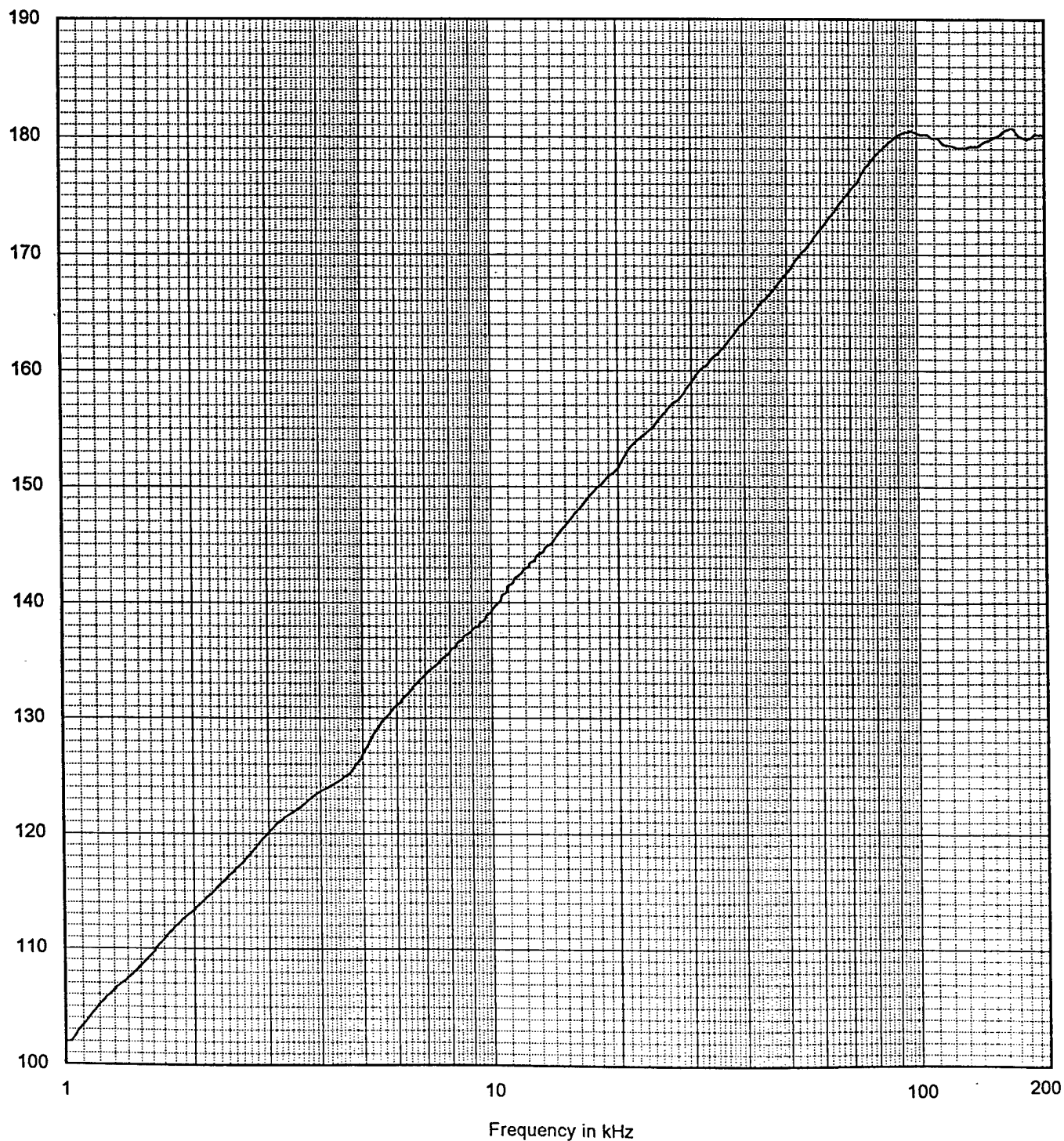
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 10-54

Pressure at one meter per volt applied at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)



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## DIRECTIONAL RESPONSE

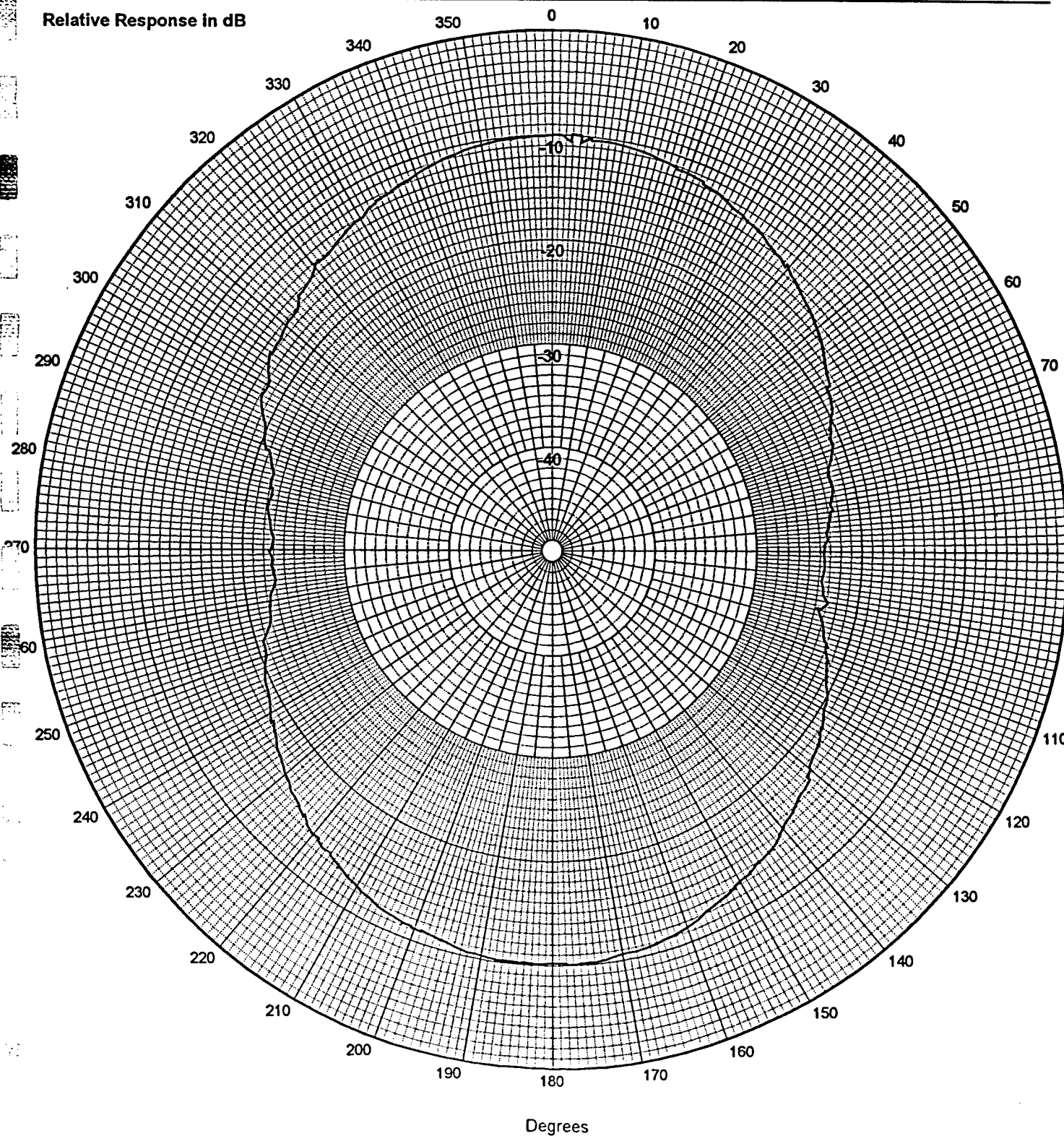
Piezocomposite Transducer Serial 10 - 54

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 5.0 kHz

Relative Response in dB





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## DIRECTIONAL RESPONSE

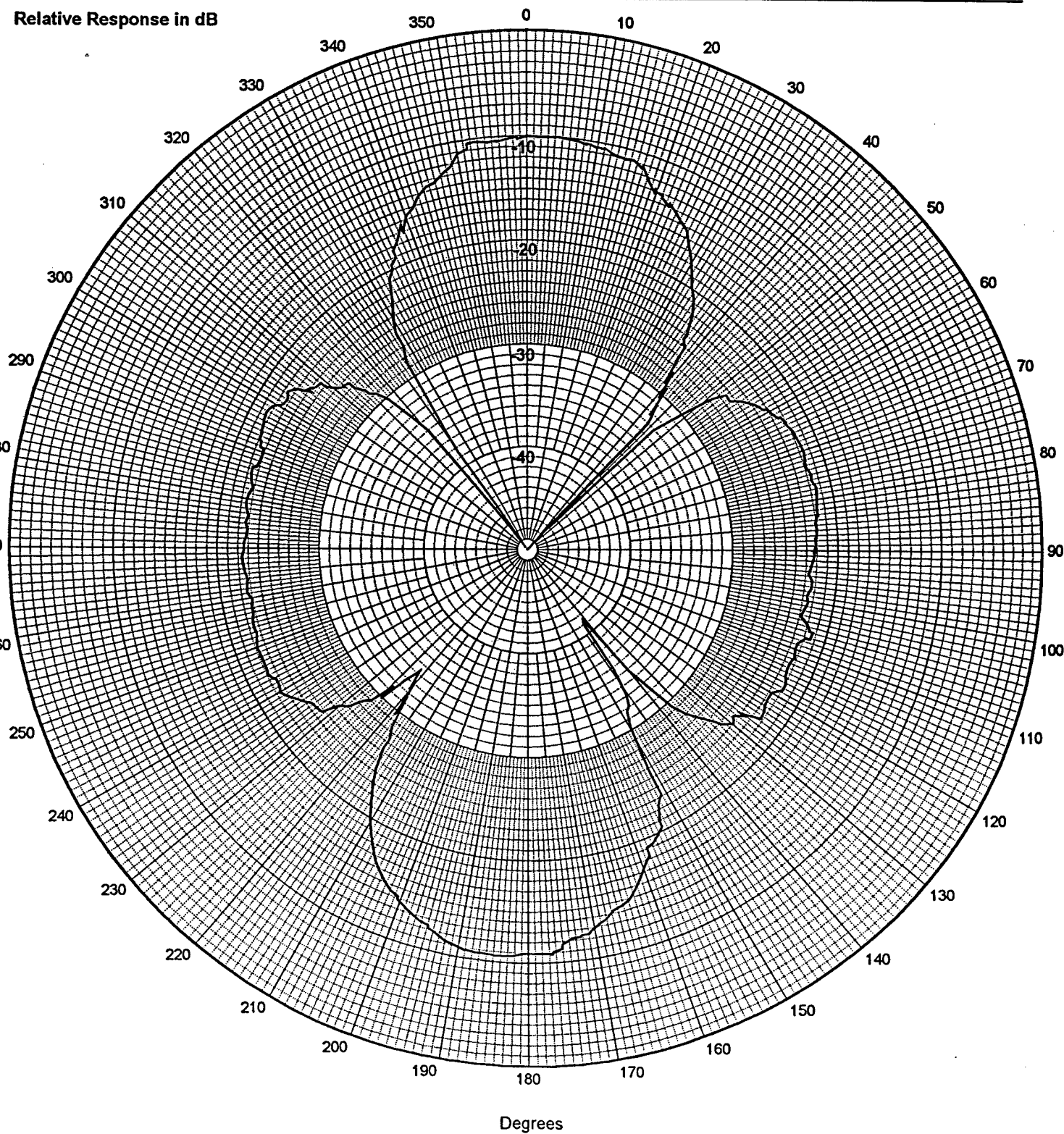
Piezocomposite Transducer Serial 10 - 54

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 10 kHz

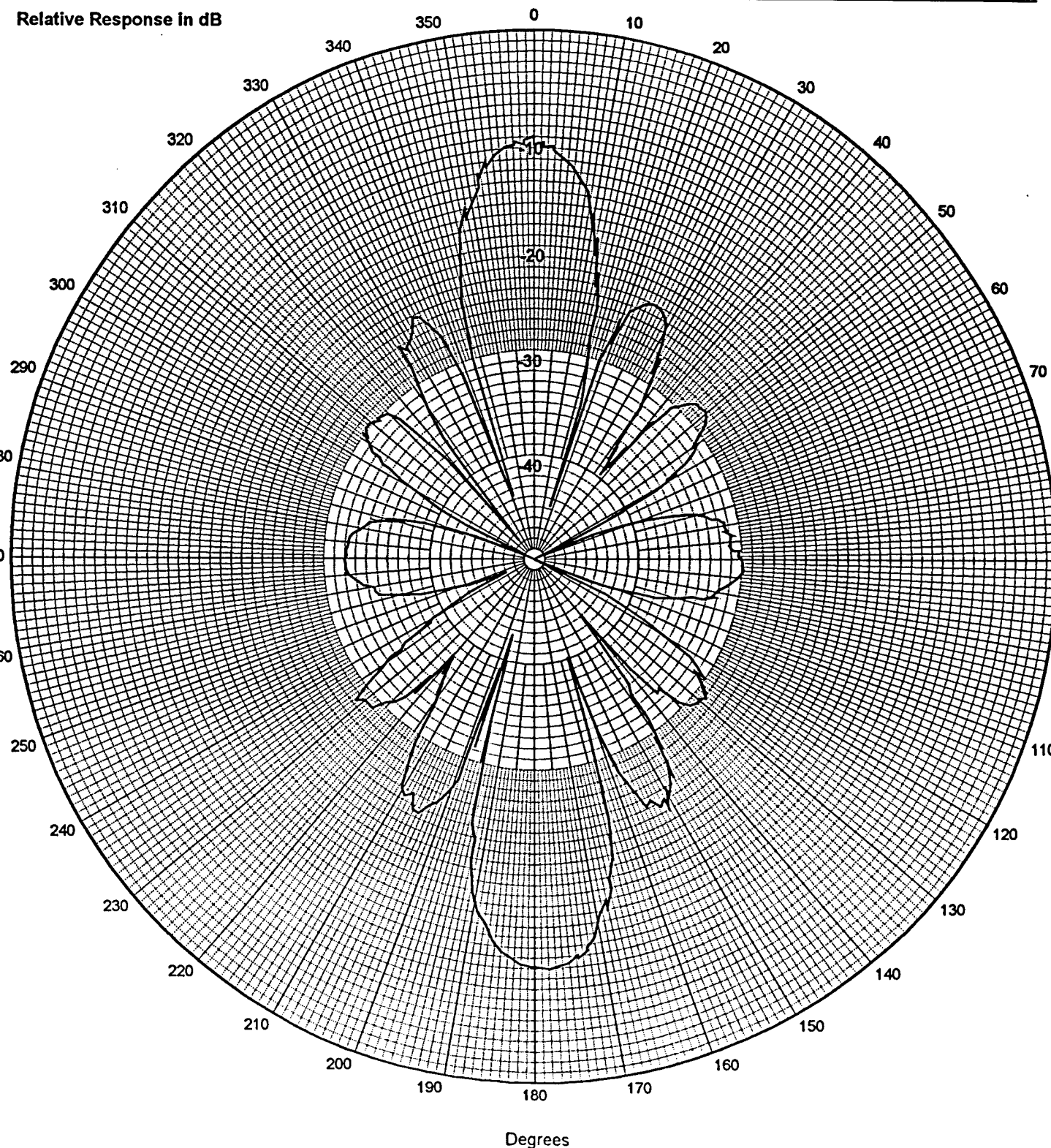
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 54  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 20 kHz

Relative Response in dB



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USRD NO: 0851-24  
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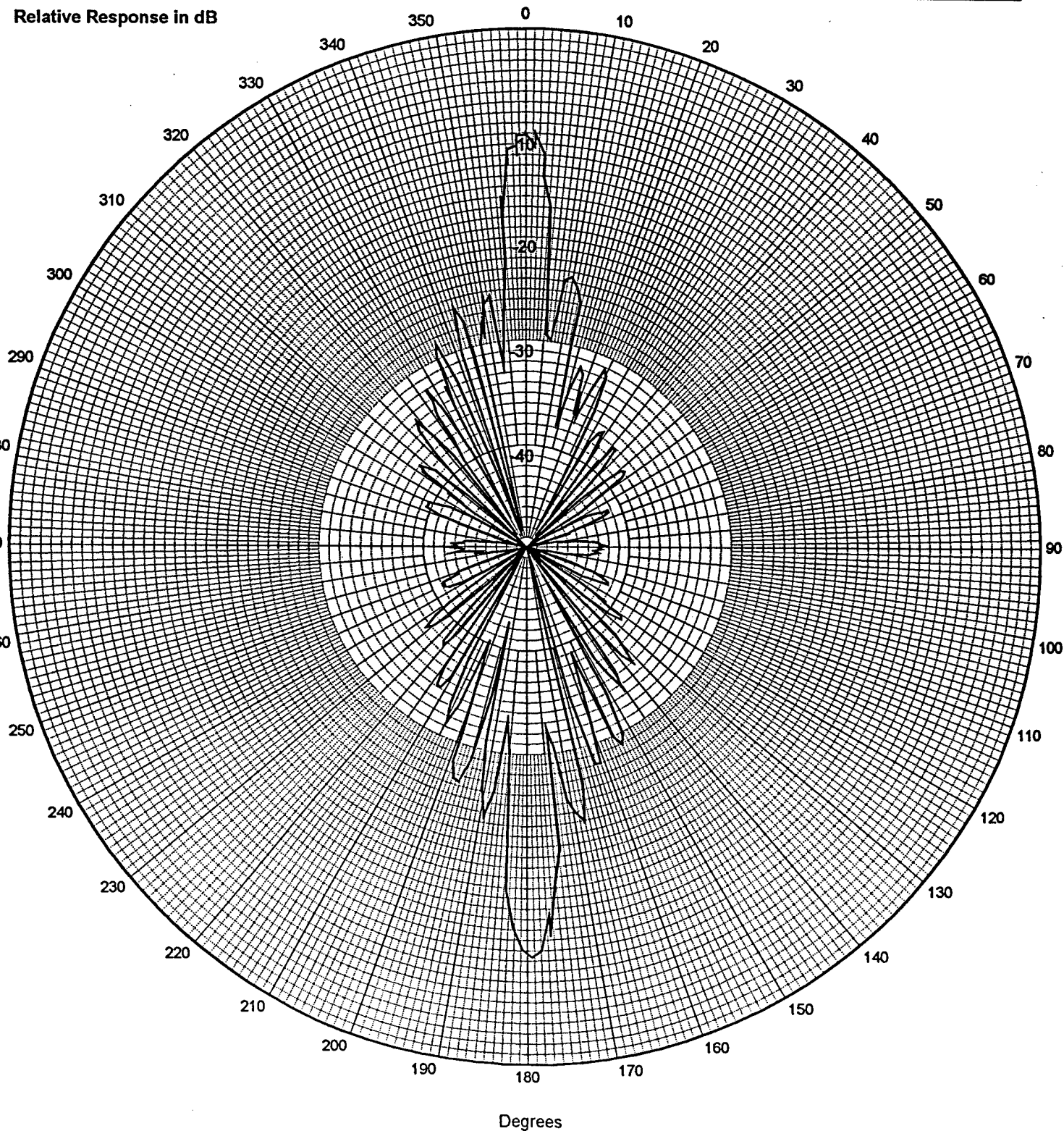
## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 54

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 50 kHz



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USRD NO: 0851-25  
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## DIRECTIONAL RESPONSE

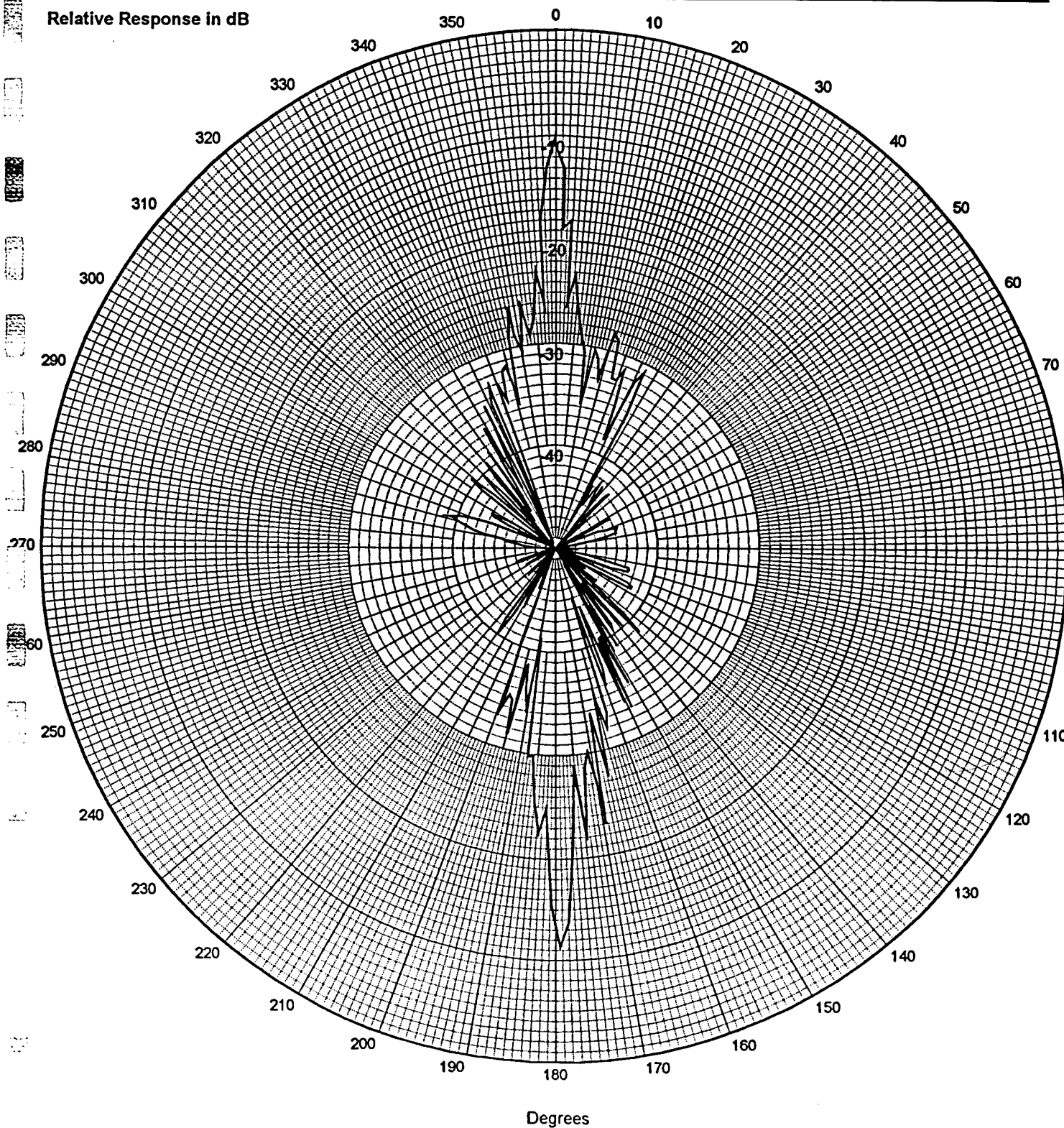
Piezocomposite Transducer Serial 10 - 54

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 100 kHz

Relative Response in dB





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USRD NO: 0851-26  
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## DIRECTIONAL RESPONSE

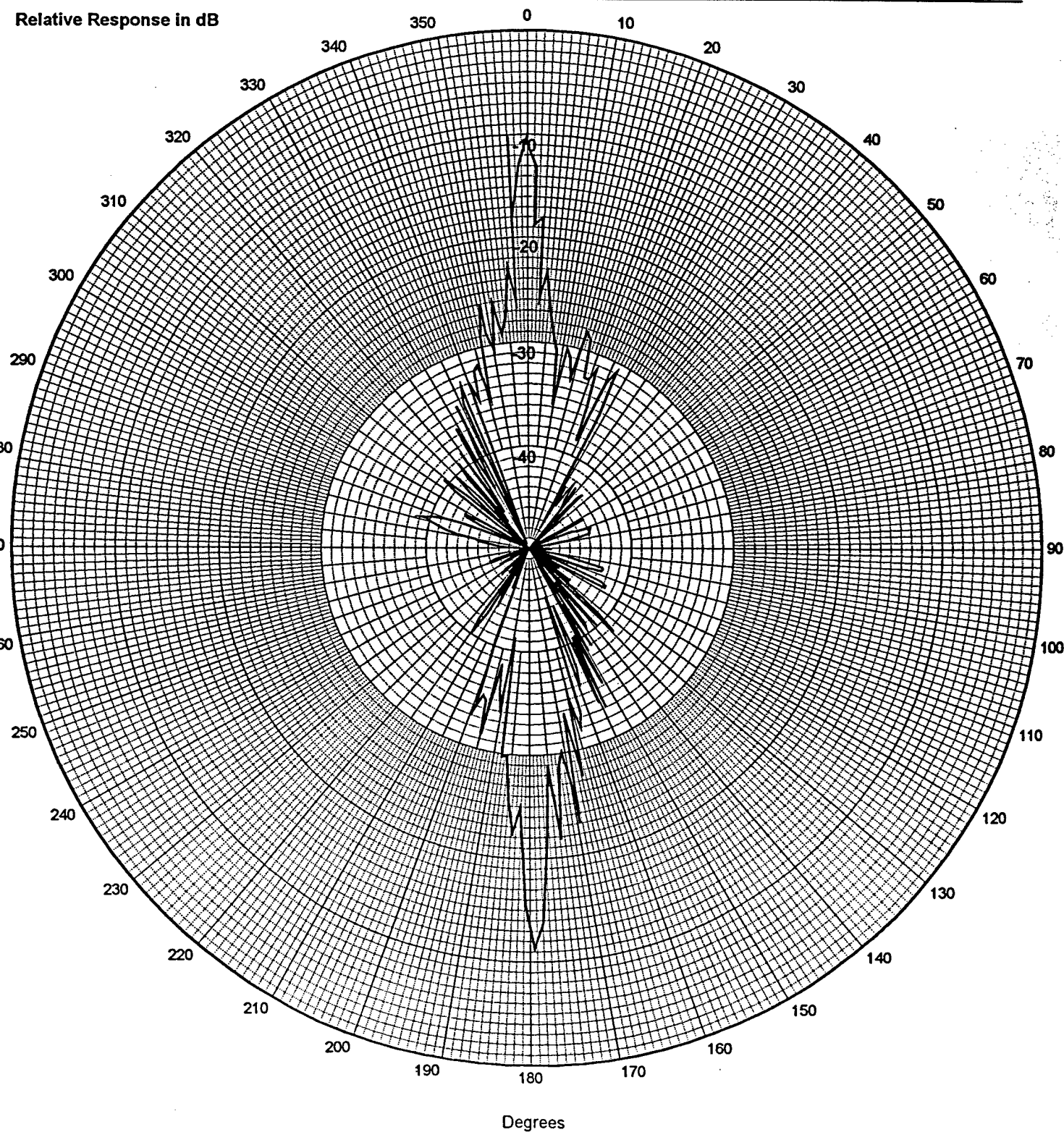
Piezocomposite Transducer Serial 10 - 54

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 200 kHz

Relative Response in dB



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USRD NO: 0851-27  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

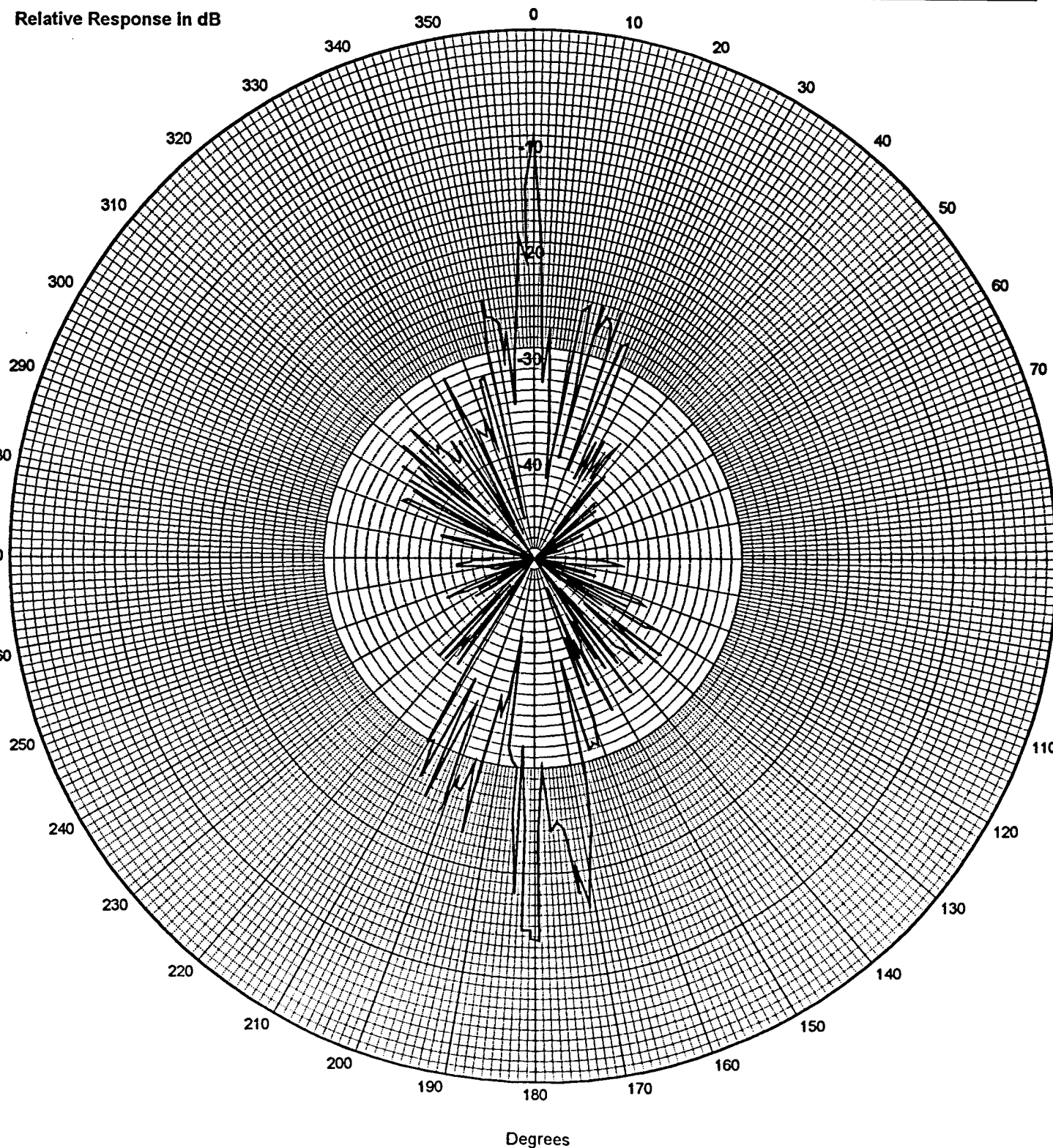
Piezocomposite Transducer Serial 10 - 54

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 300 kHz

Relative Response in dB



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USRD NO. 0851-28  
LAKE FACILITY  
AUG 1996

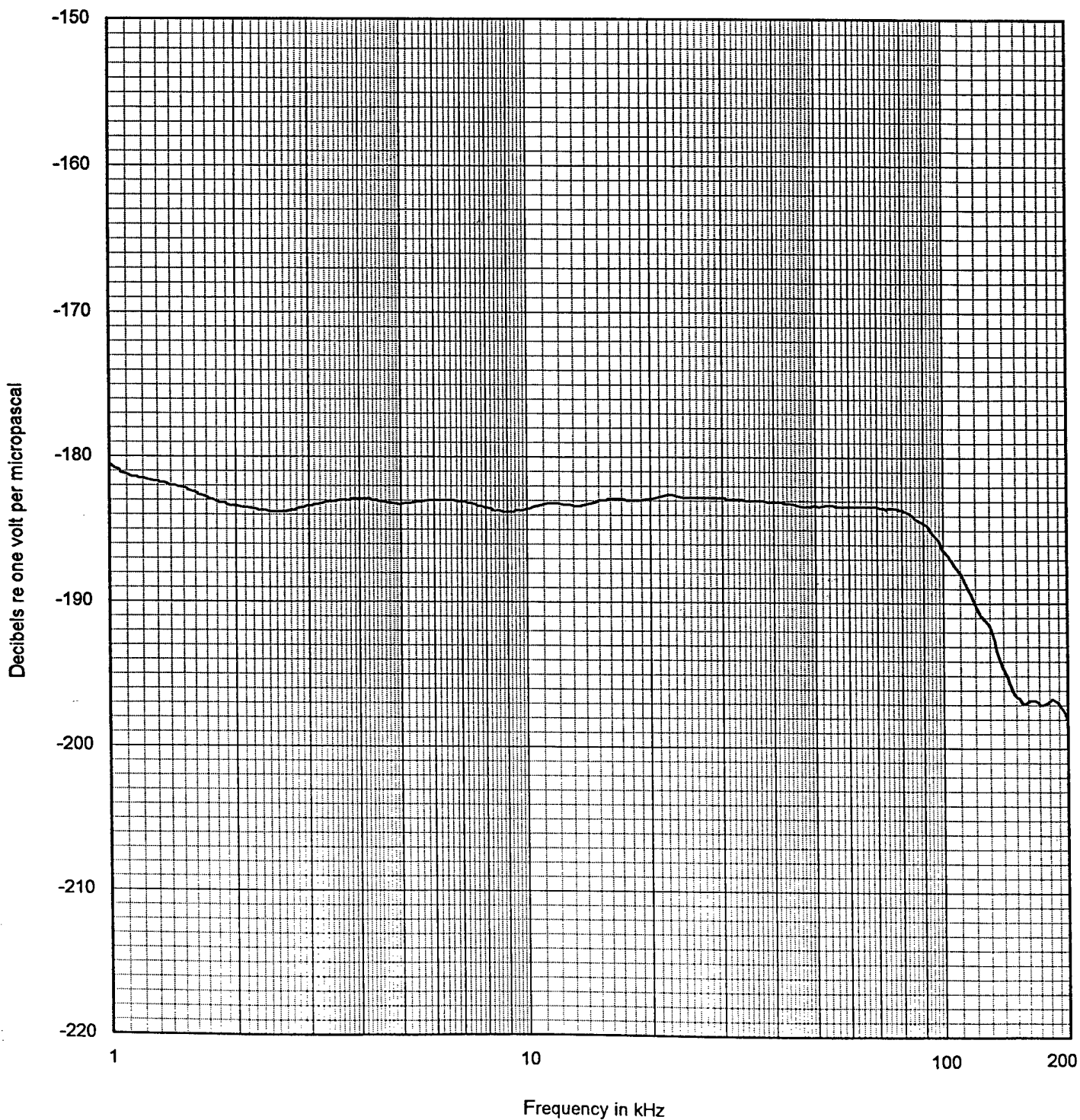
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 10-55

Open-circuit voltage measured at end of 15.0 -m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 ( 38 kPa )



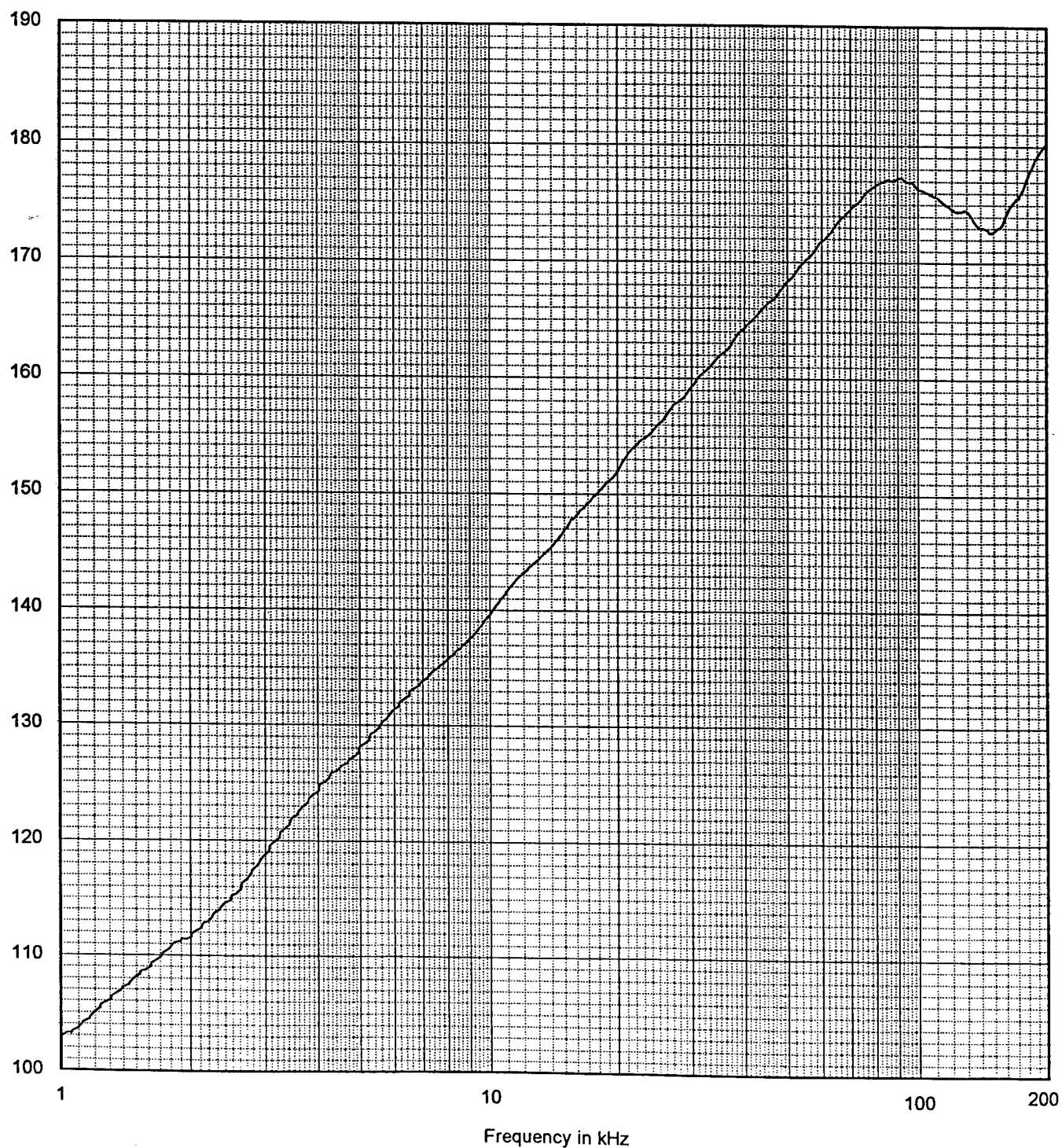
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 10-55

Pressure at one meter per volt applied at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)





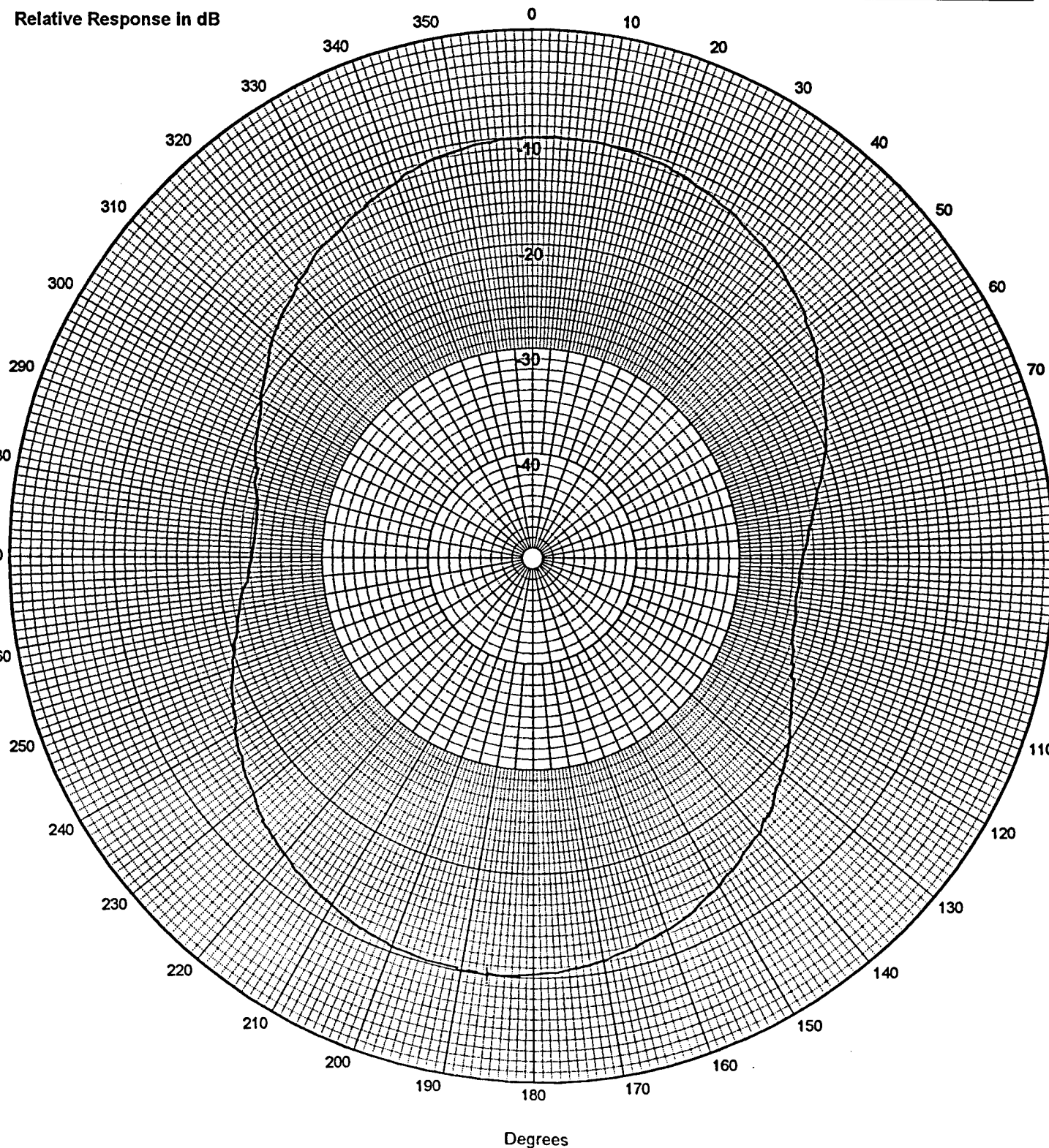
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-30  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 55  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 5.0 kHz

Relative Response in dB



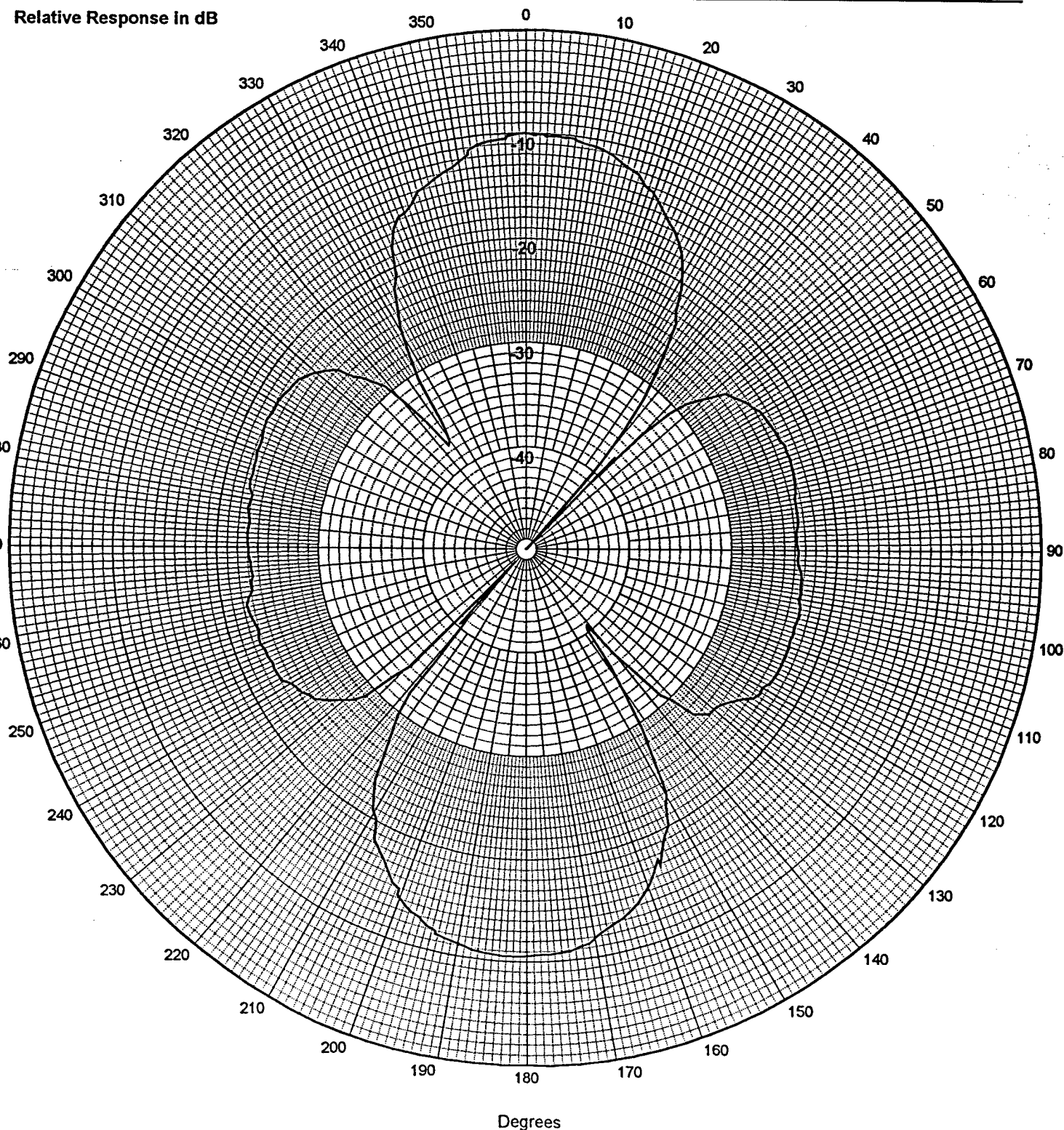
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-31  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 55  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 10 kHz

Relative Response in dB



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USRD NO: 0851-32  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

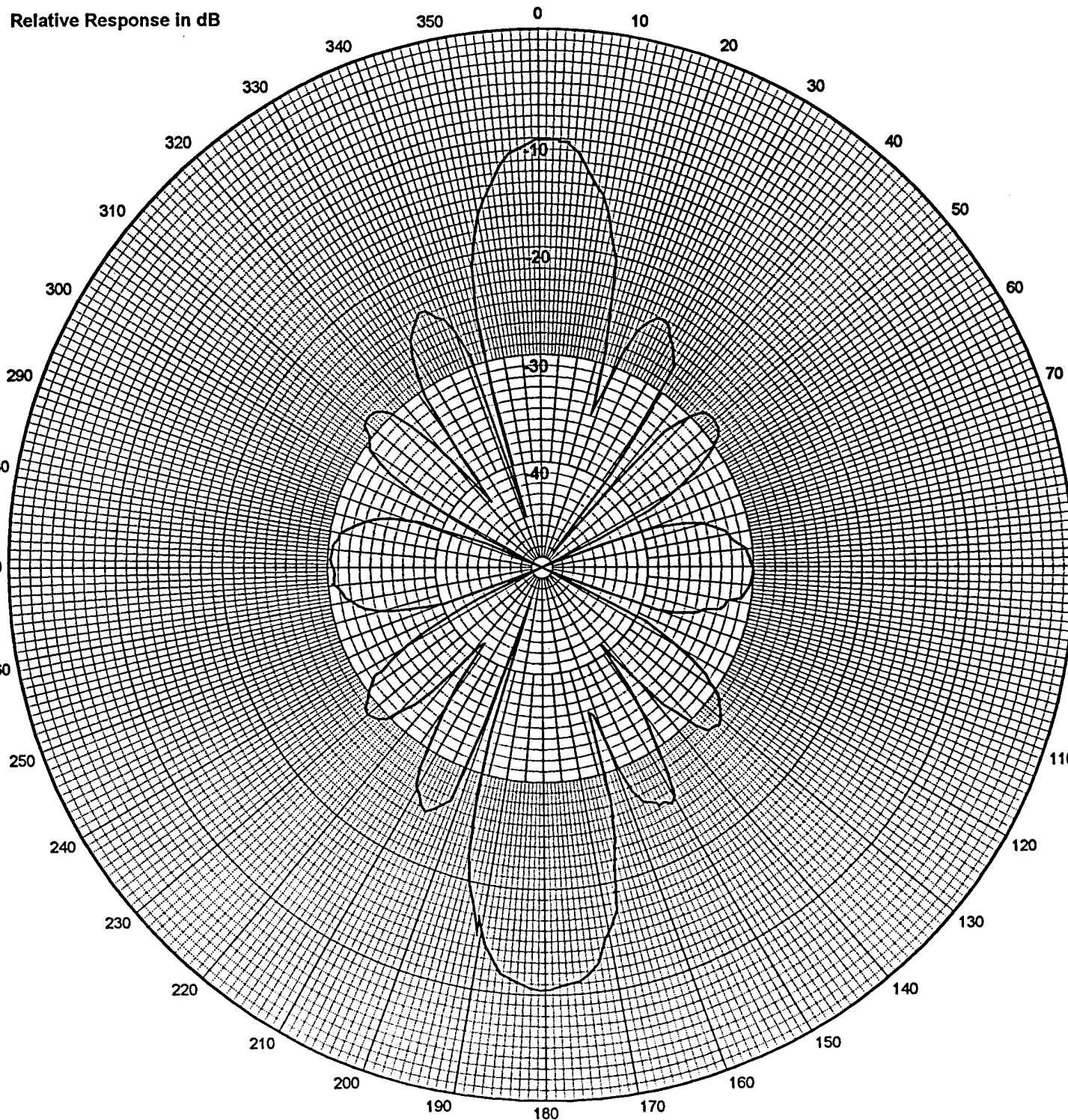
Piezocomposite Transducer Serial 10 - 55

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 20 kHz

Relative Response in dB



Degrees

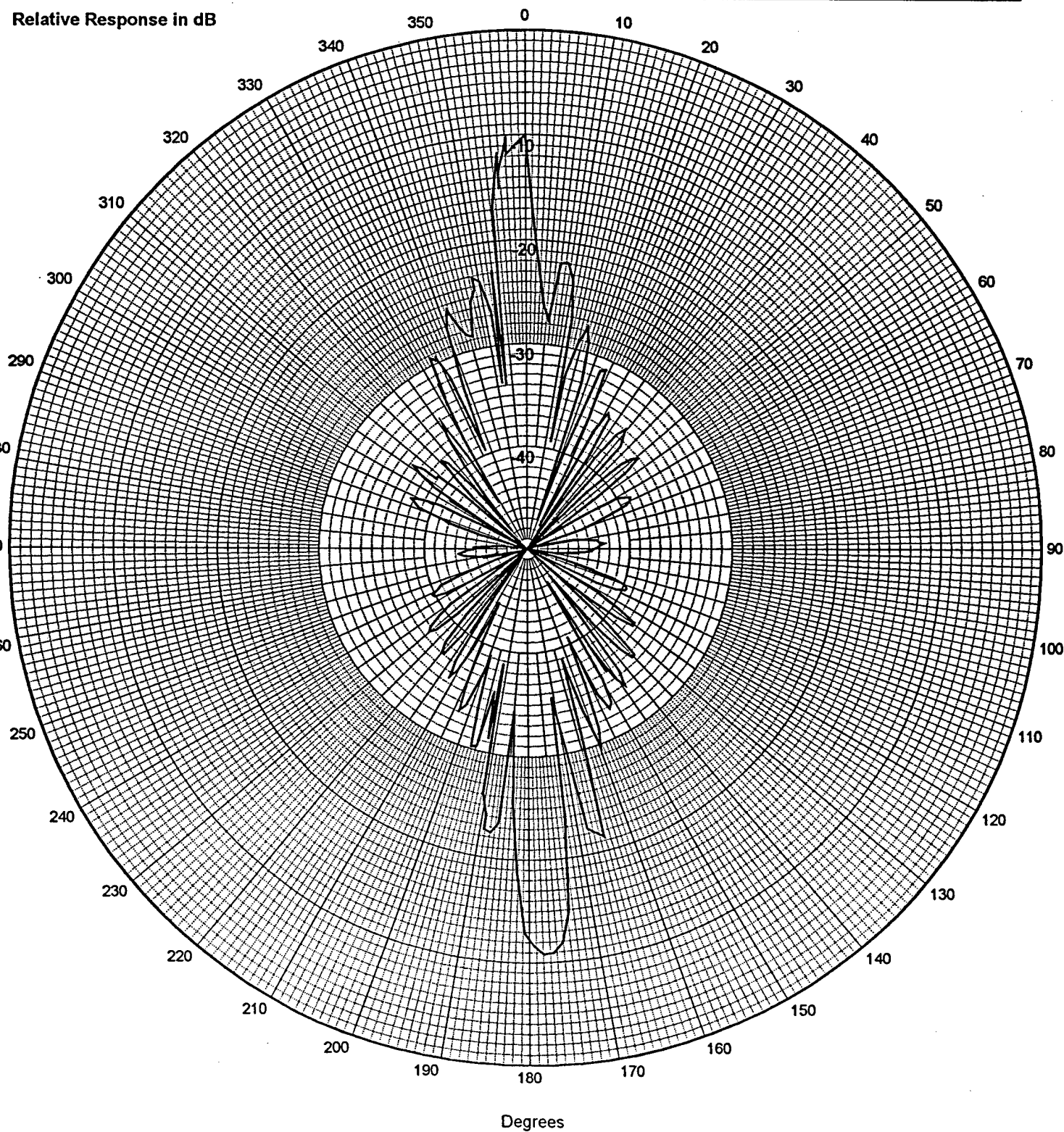
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-33  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 55  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 50 kHz

Relative Response in dB





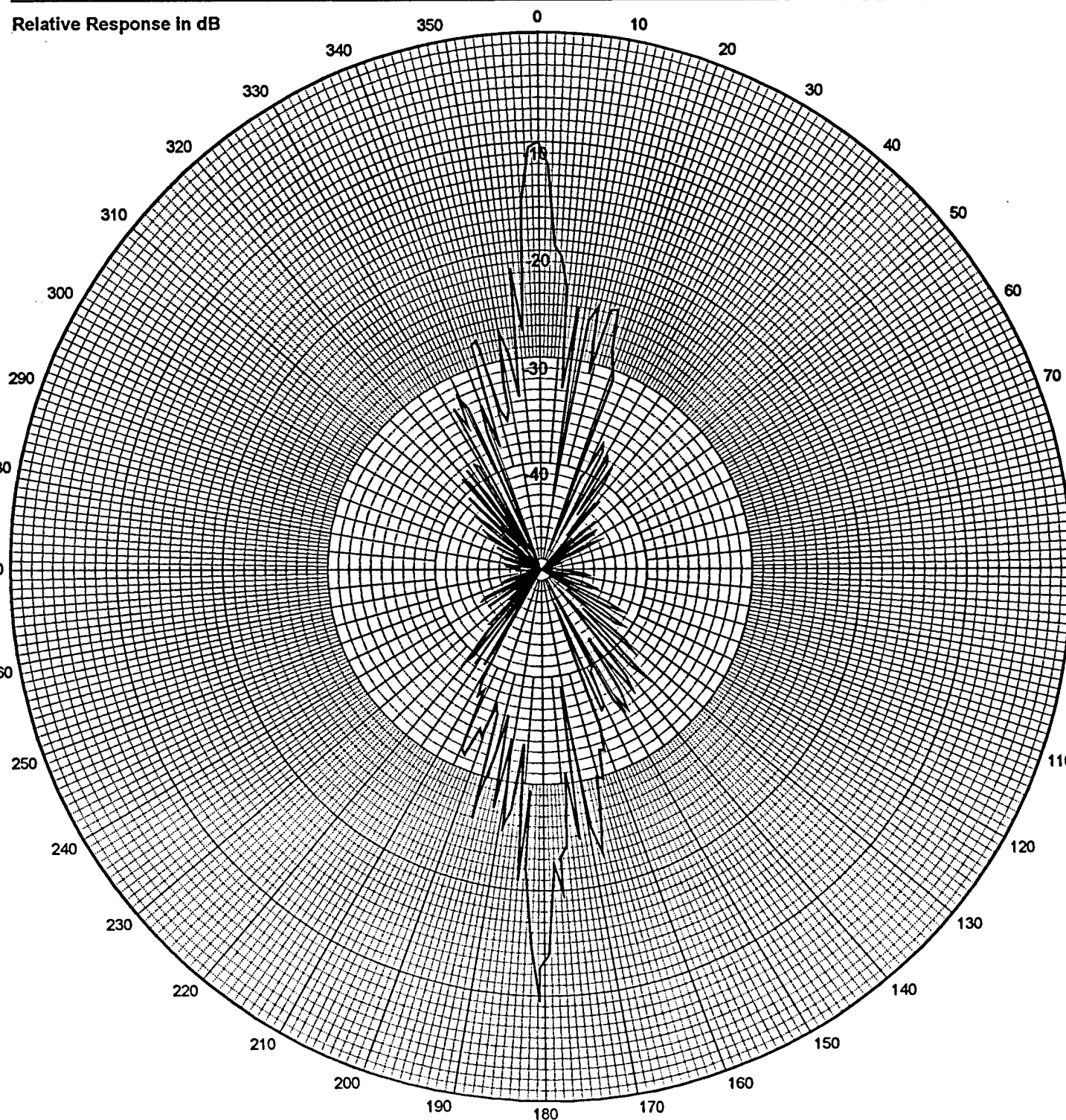
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-34  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 55  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 100 kHz

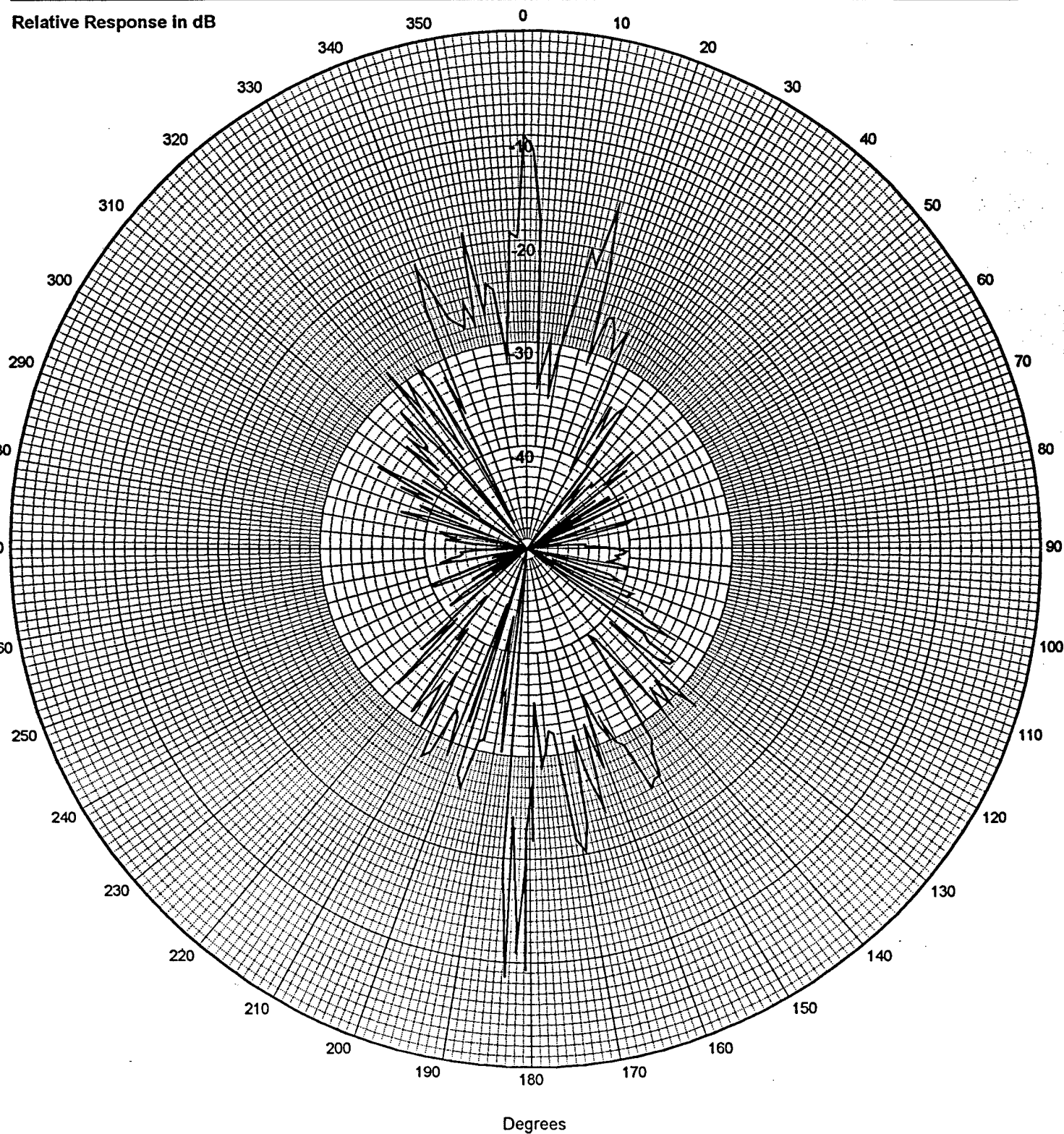
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 55  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 200 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

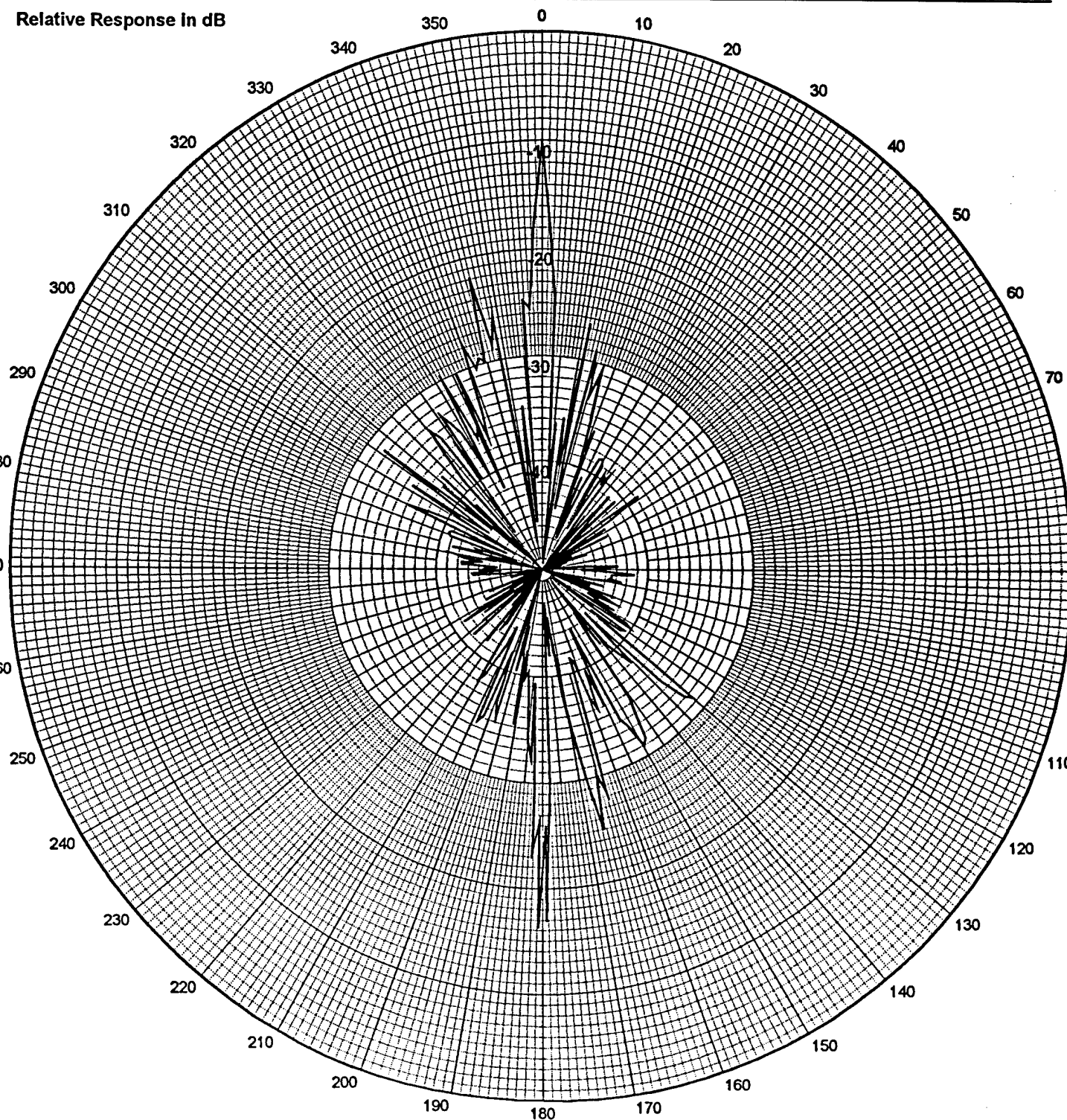
Piezocomposite Transducer Serial 10 - 55

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 300 kHz

Relative Response in dB



Degrees

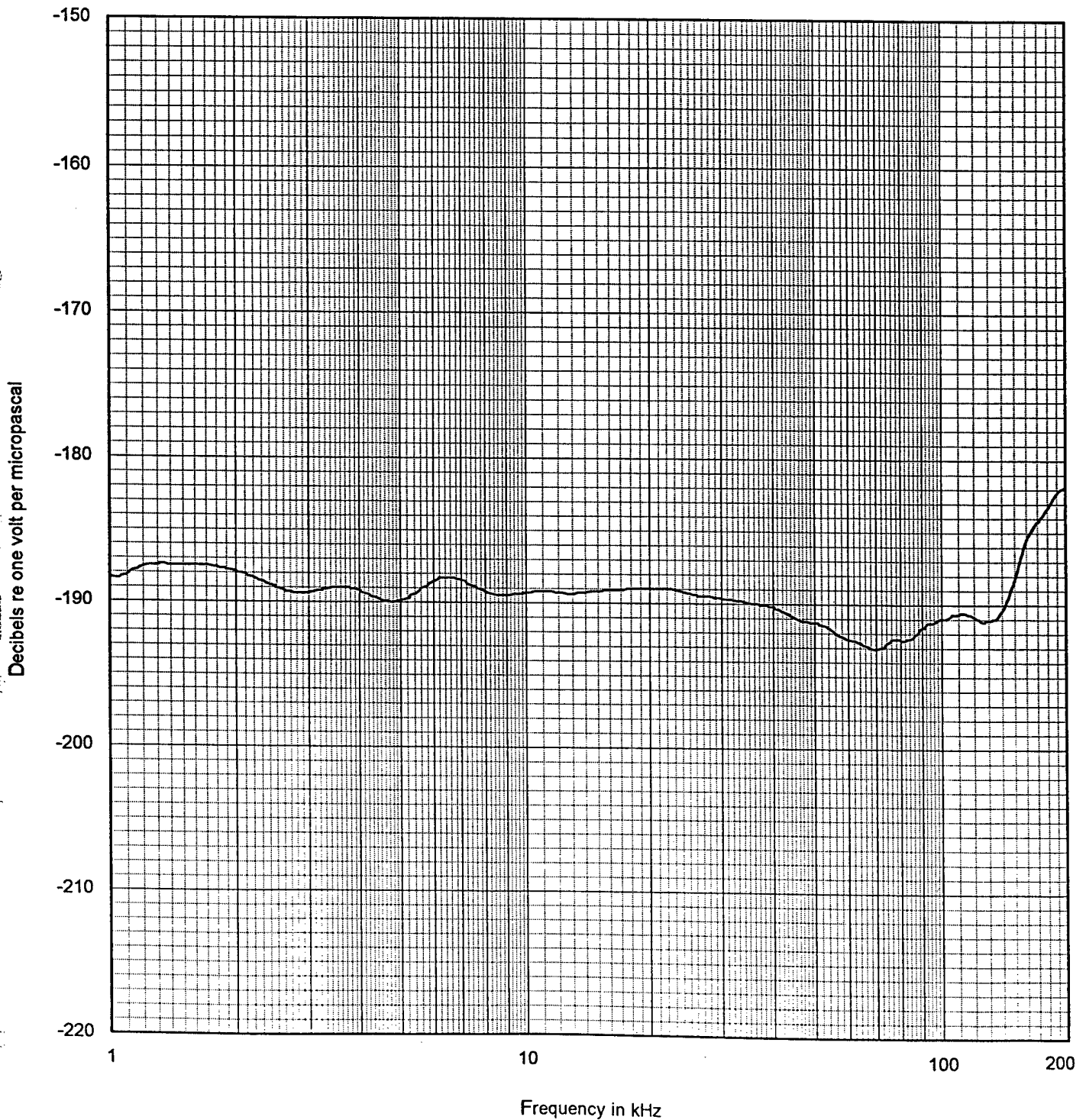
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 10-56

Open-circuit voltage measured at end of 15.0 -m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 ( 38 kPa )





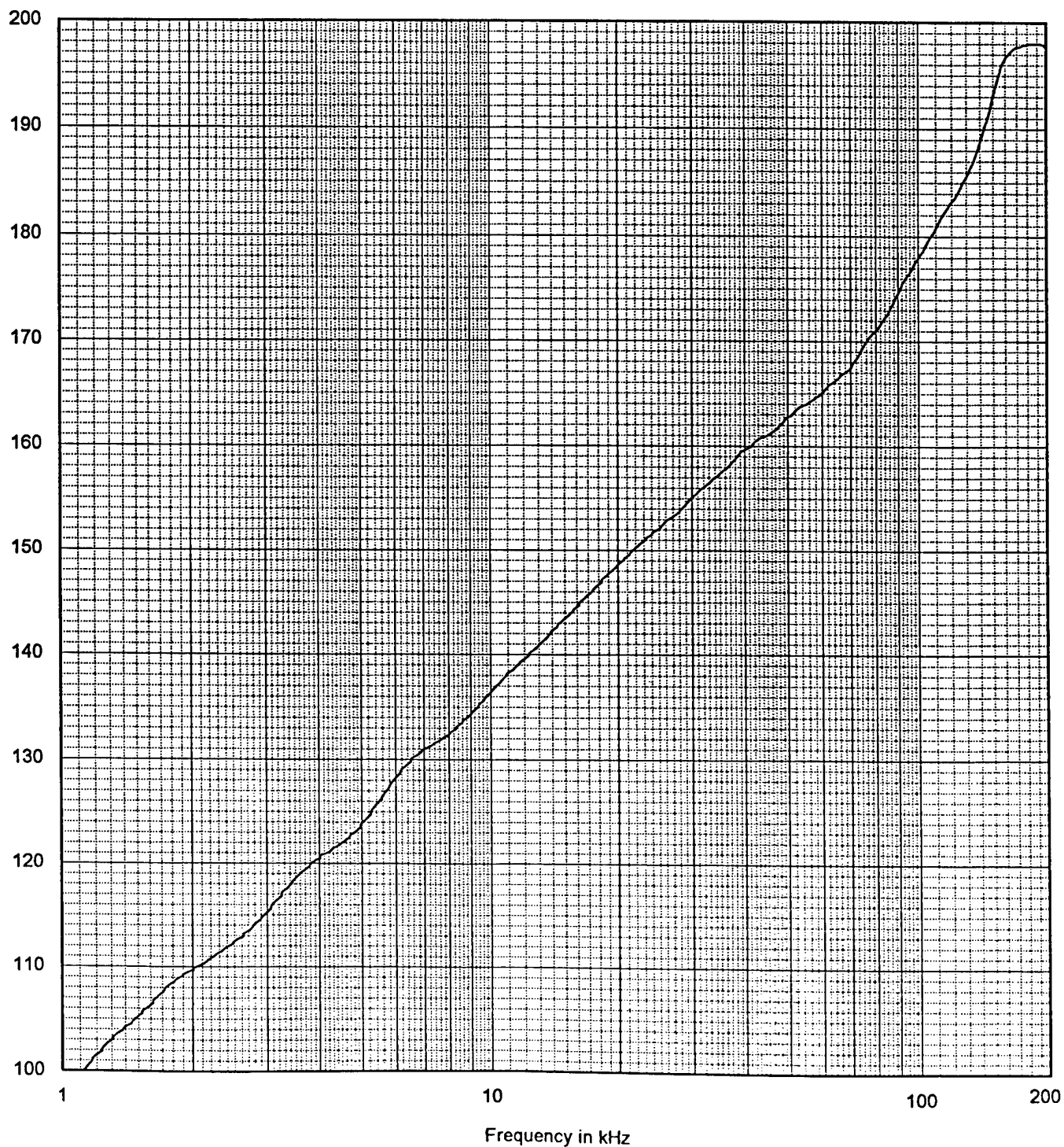
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 10-56

Pressure at one meter per volt applied at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)



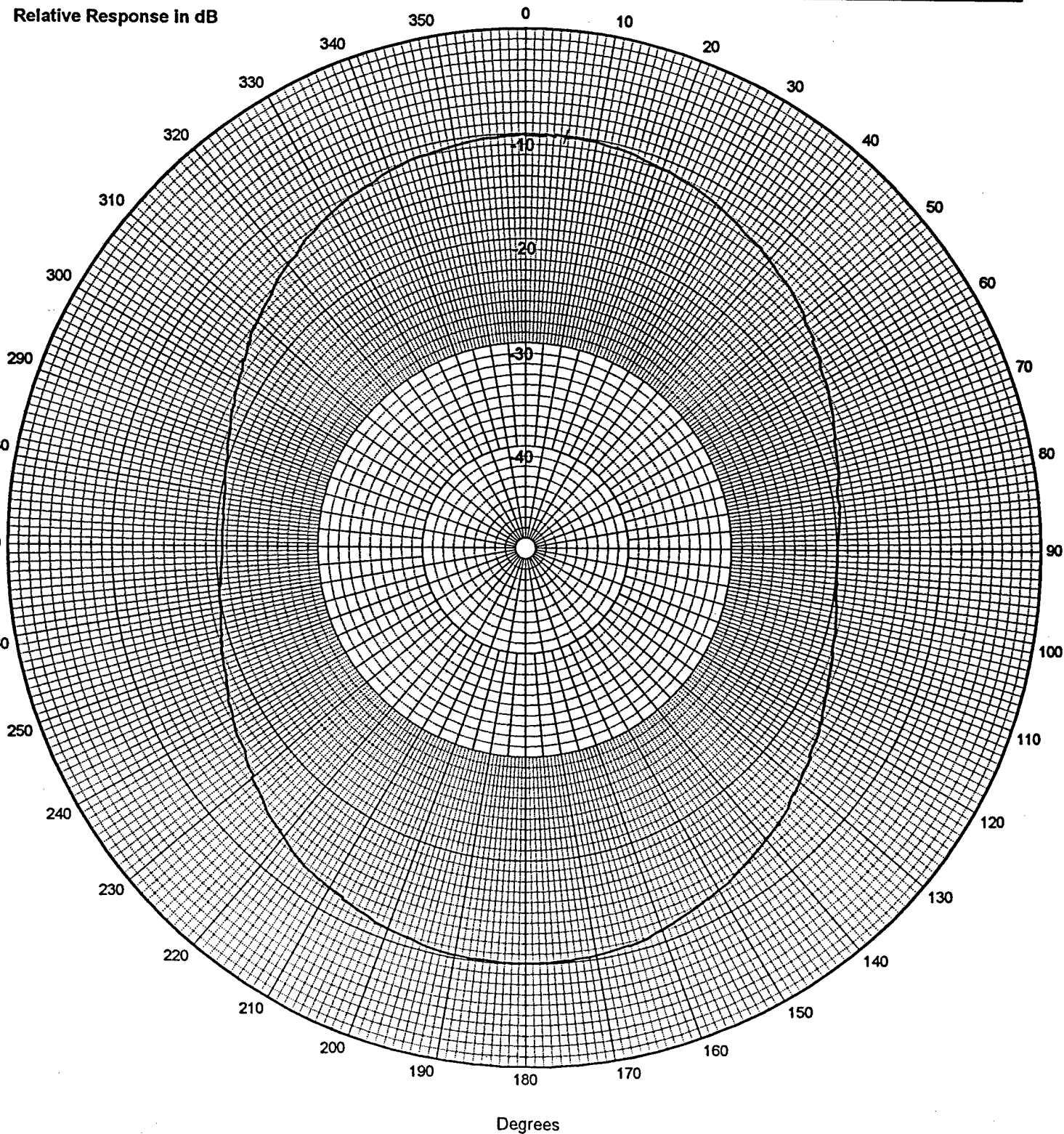
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-39  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 56  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 5.0 kHz

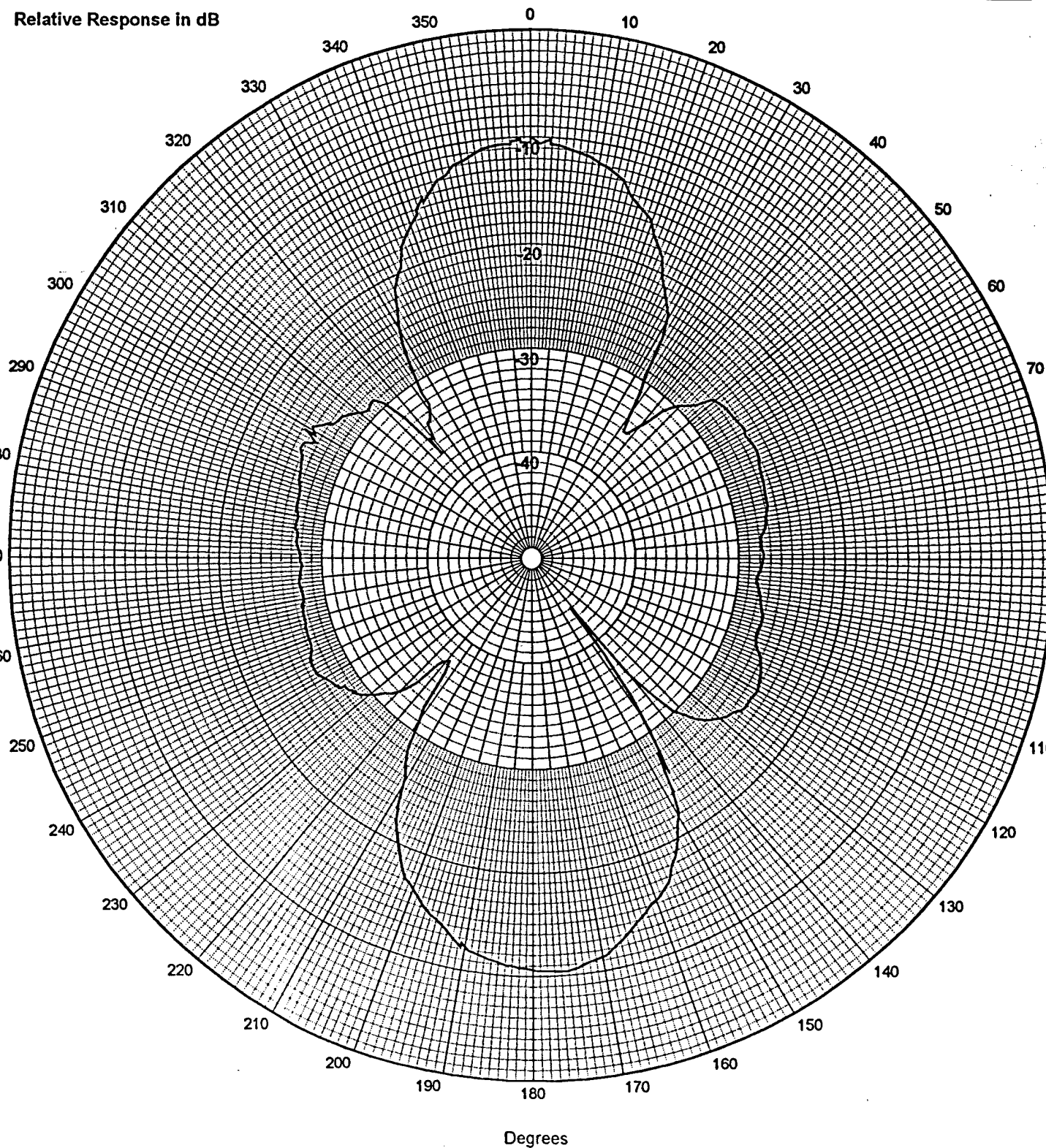
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 56  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 10 kHz

Relative Response in dB



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USRD NO: 0851-41  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

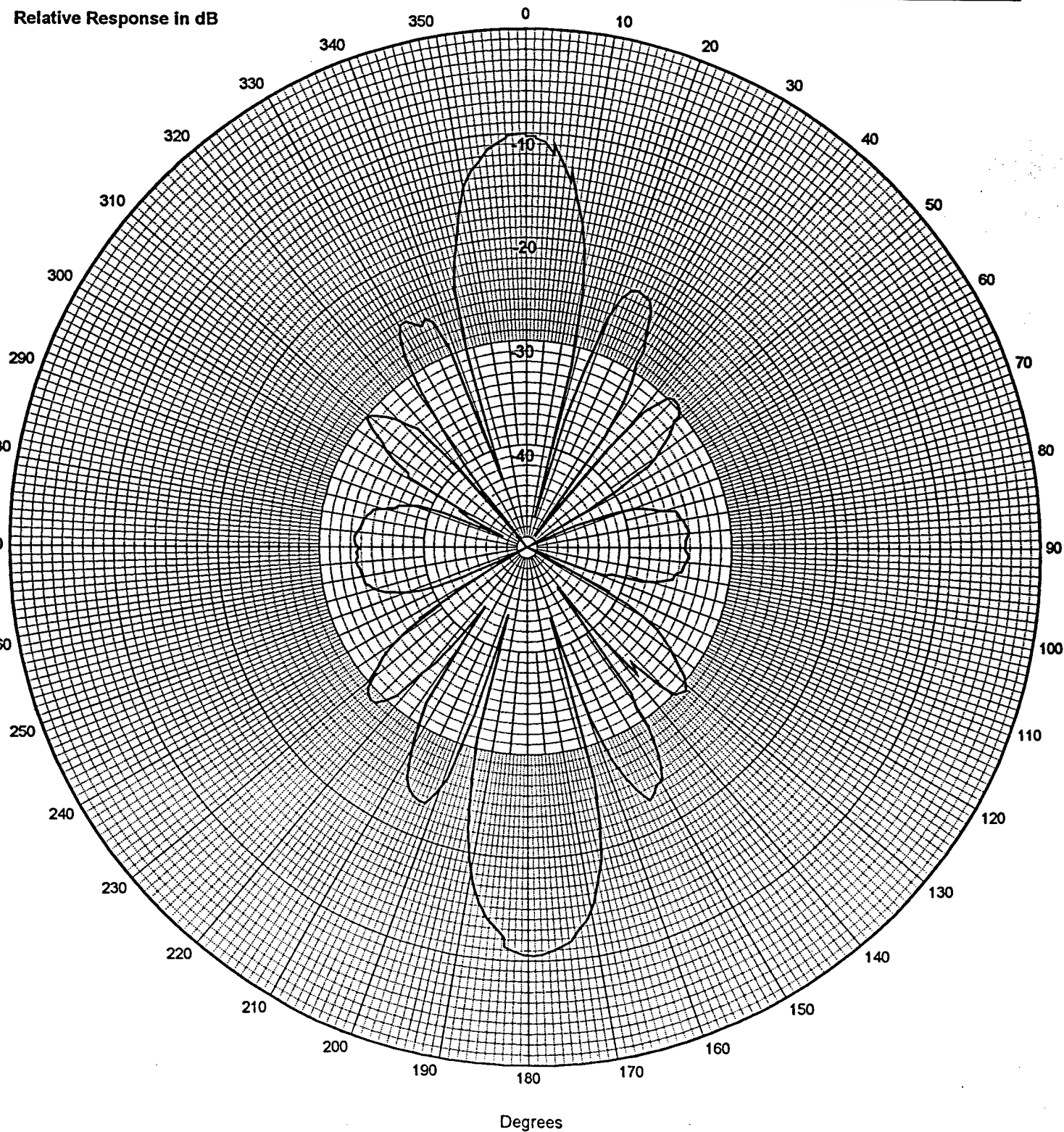
Piezocomposite Transducer Serial 10 - 56

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 20 kHz

Relative Response in dB





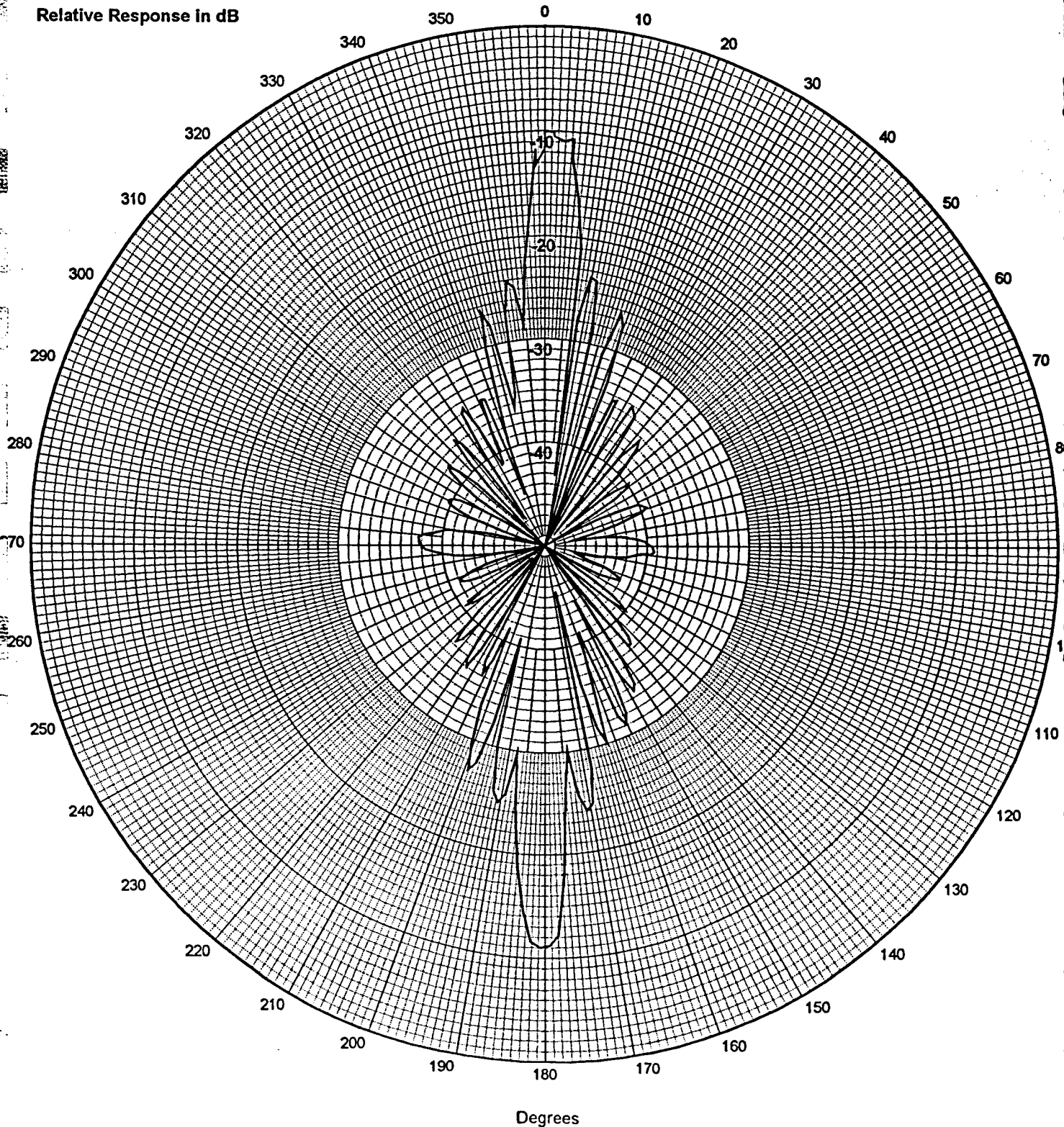
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-42  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 56  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 50 kHz

Relative Response in dB



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UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-43  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

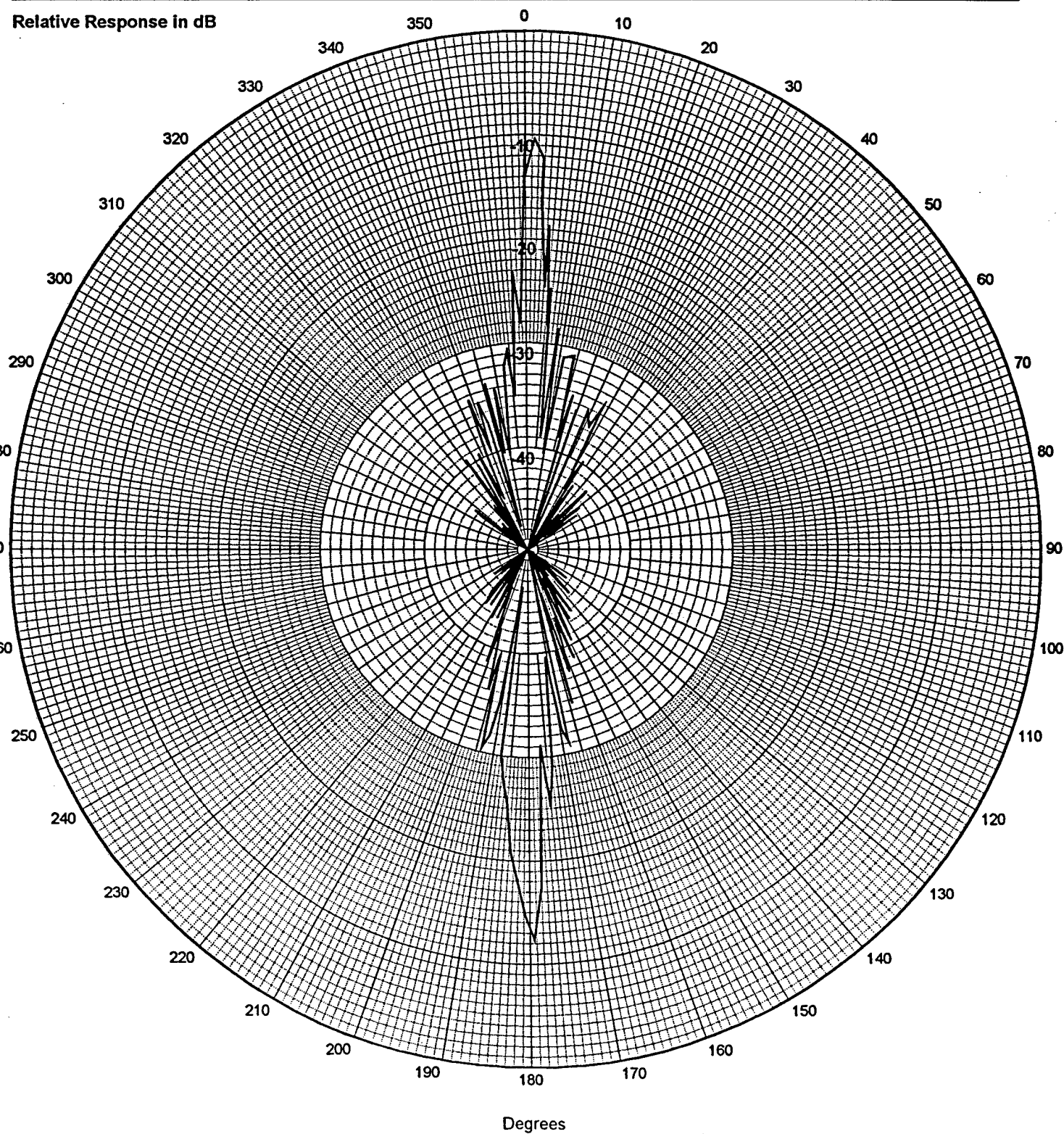
Piezocomposite Transducer Serial 10 - 56

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 100 kHz

Relative Response in dB



## DIRECTIONAL RESPONSE

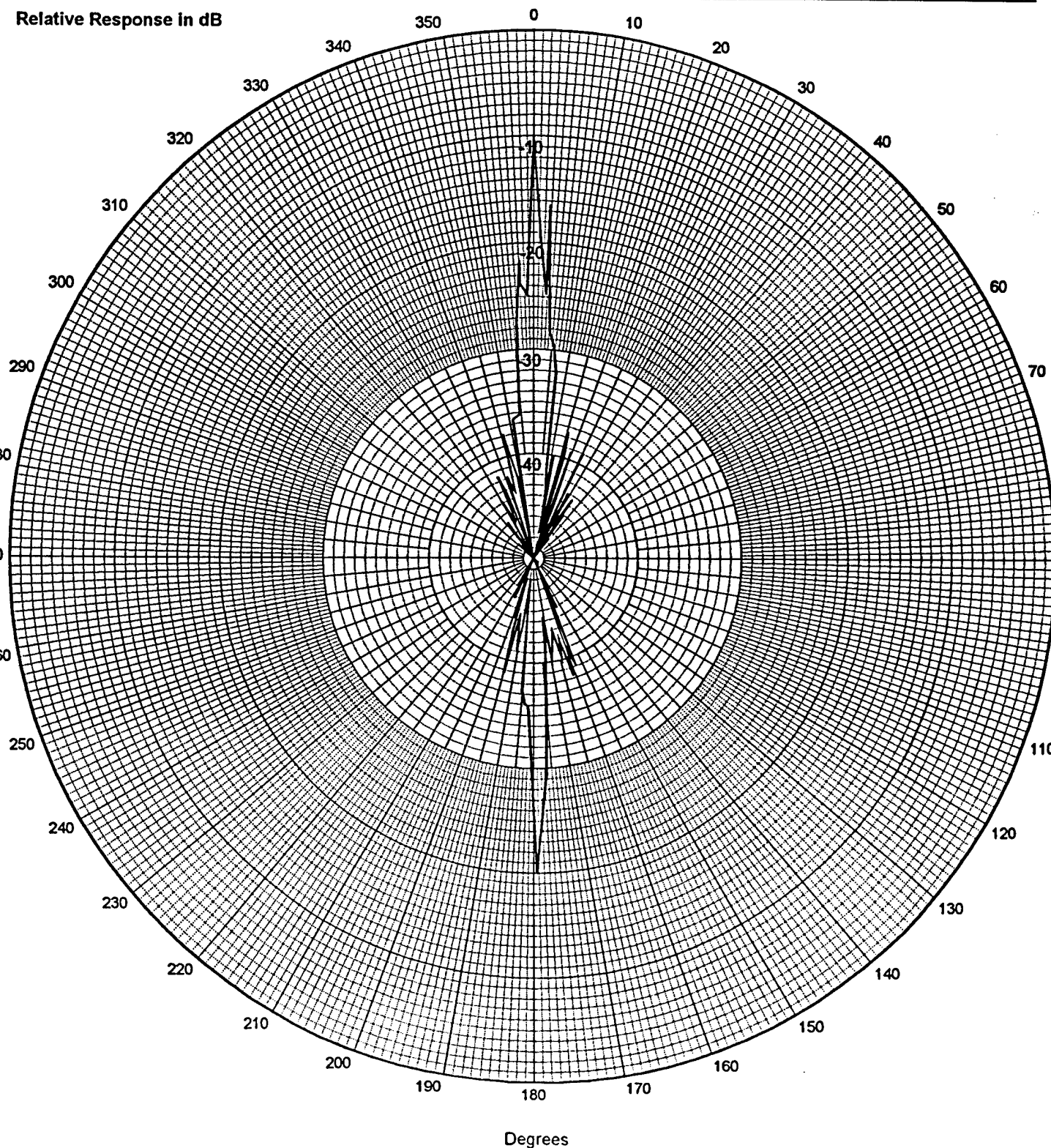
Piezocomposite Transducer Serial 10 - 56

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 200 kHz

Relative Response in dB



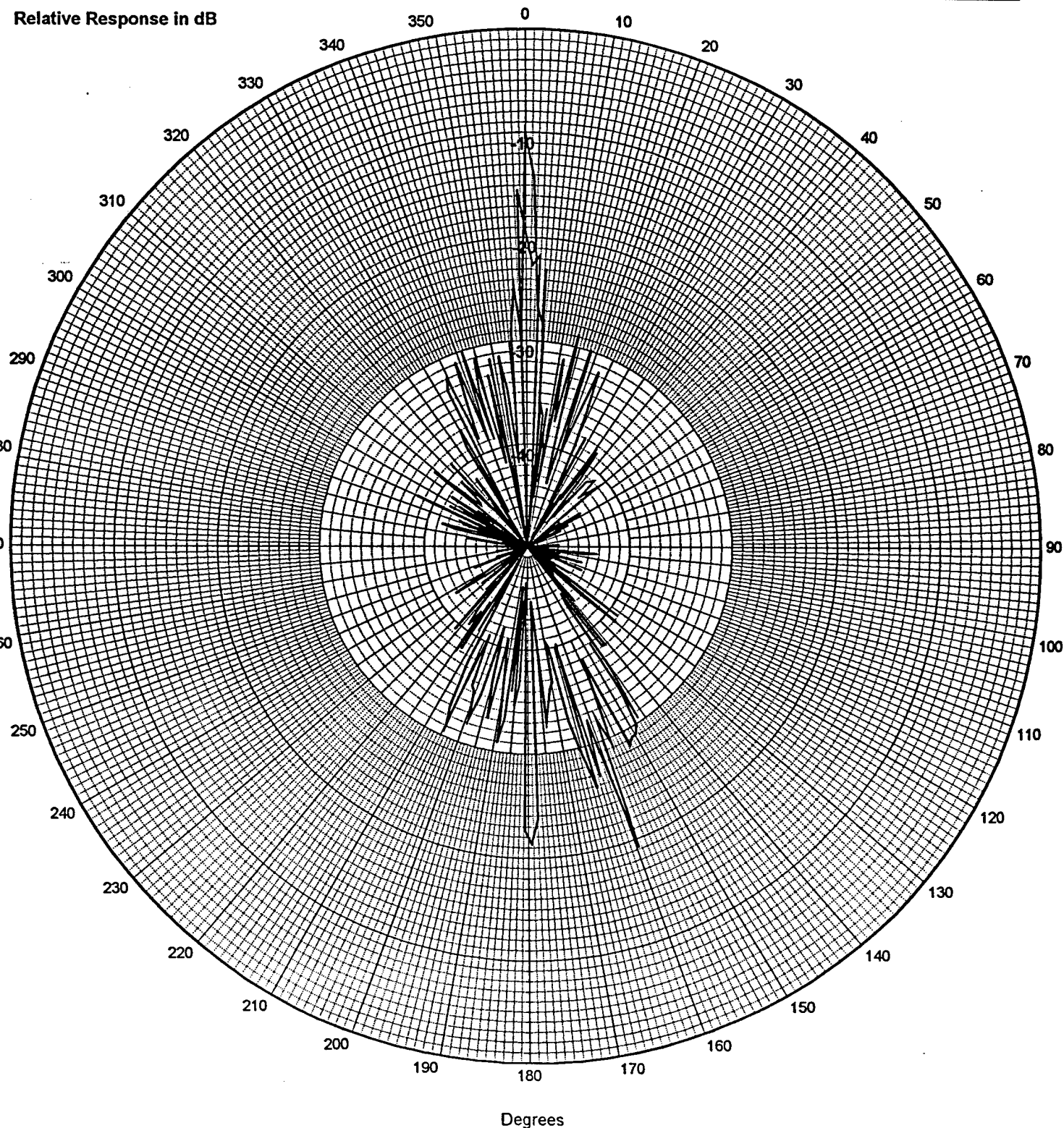
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-45  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 56  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 300 kHz

Relative Response in dB





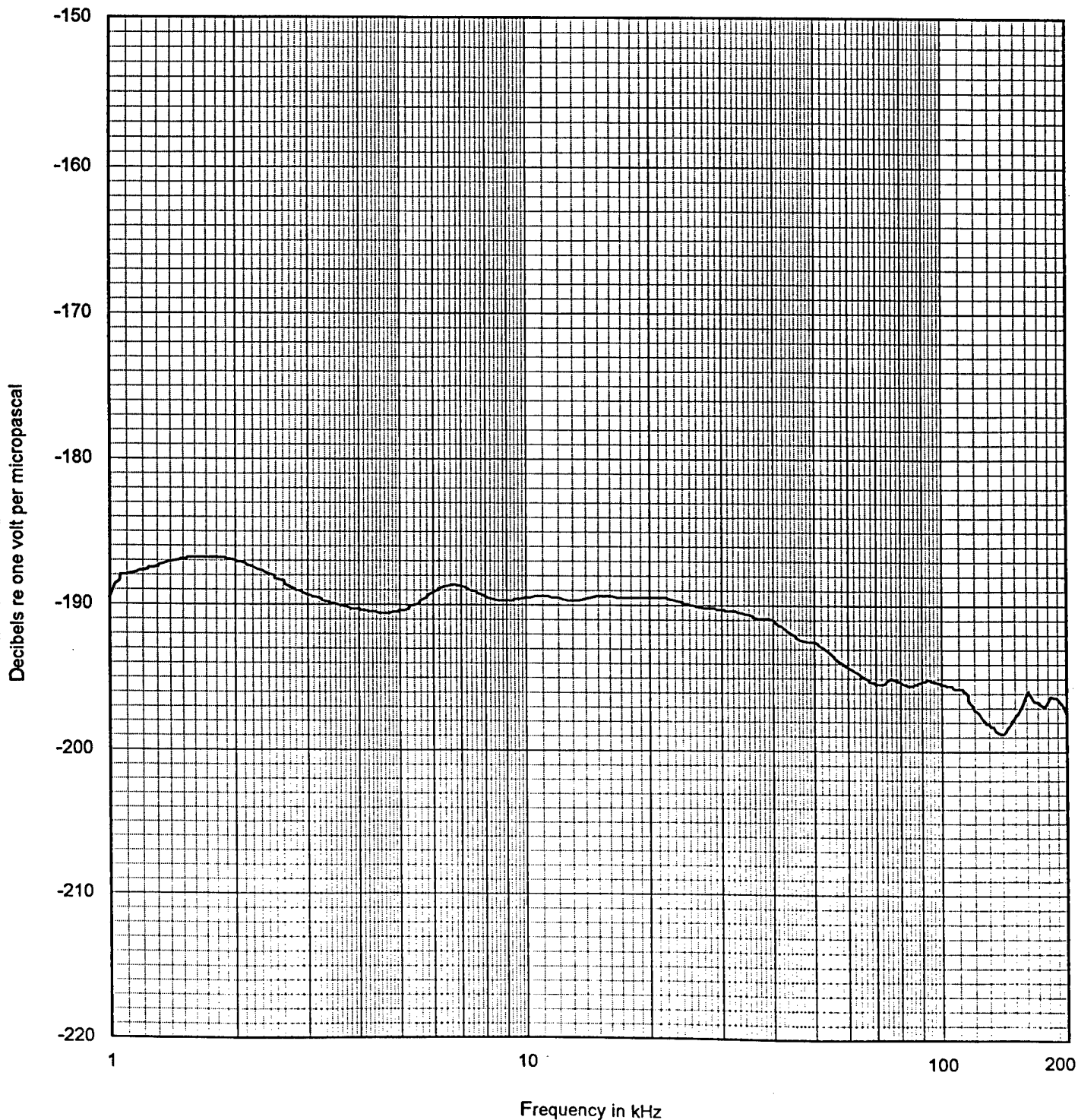
## FREE-FIELD VOLTAGE SENSITIVITY

Piezocomposite Transducer Serial 10-57

Open-circuit voltage measured at end of 15.0 -m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 ( 38 kPa )



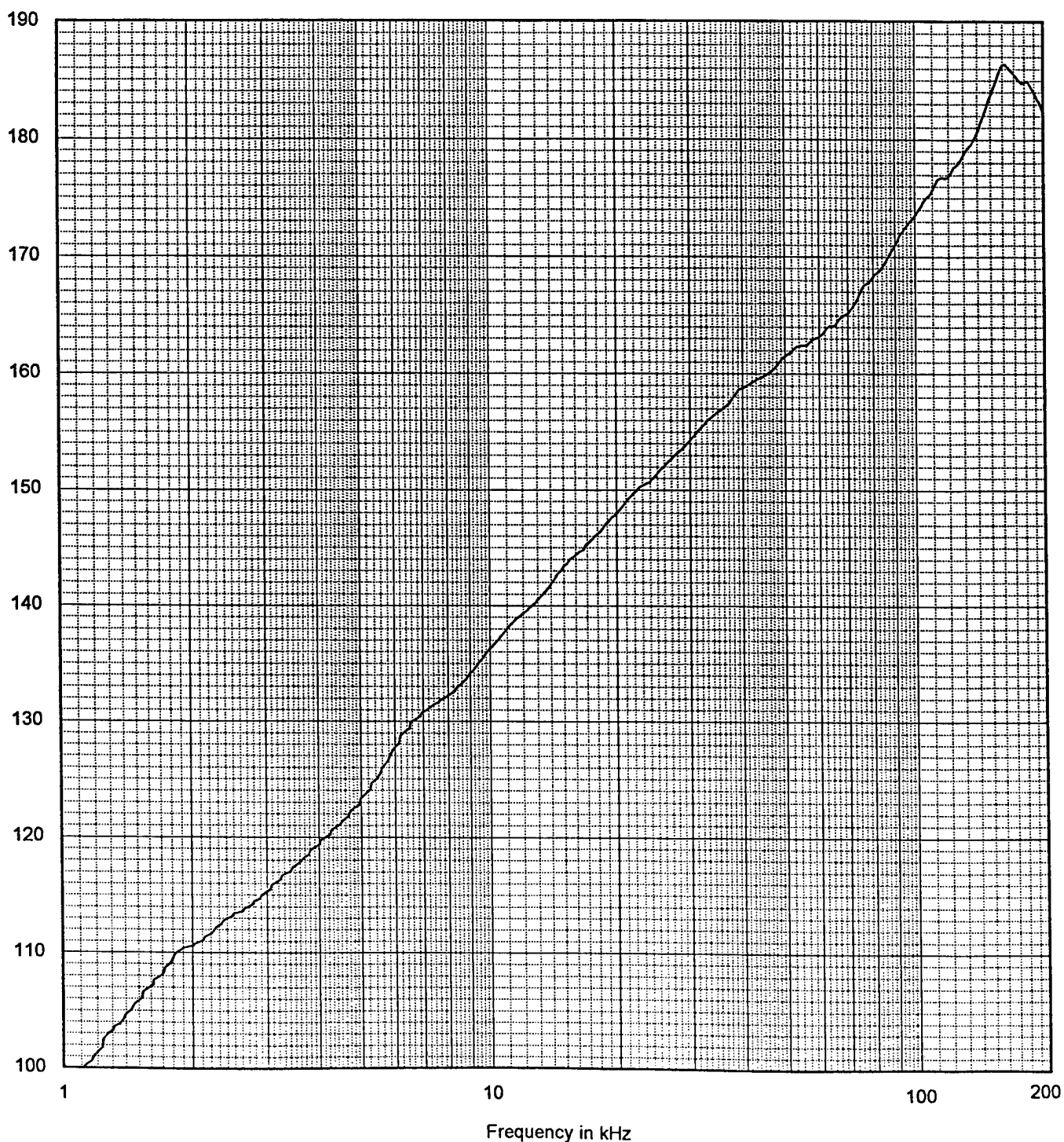
## TRANSMITTING VOLTAGE RESPONSE

Piezocomposite Transducer Serial 10-57

Pressure at one meter per volt applied at end of 15.0-m cable; Unbalanced

Water Temp: 30° C

Depth: 3.9 m (38 kPa)



## DIRECTIONAL RESPONSE

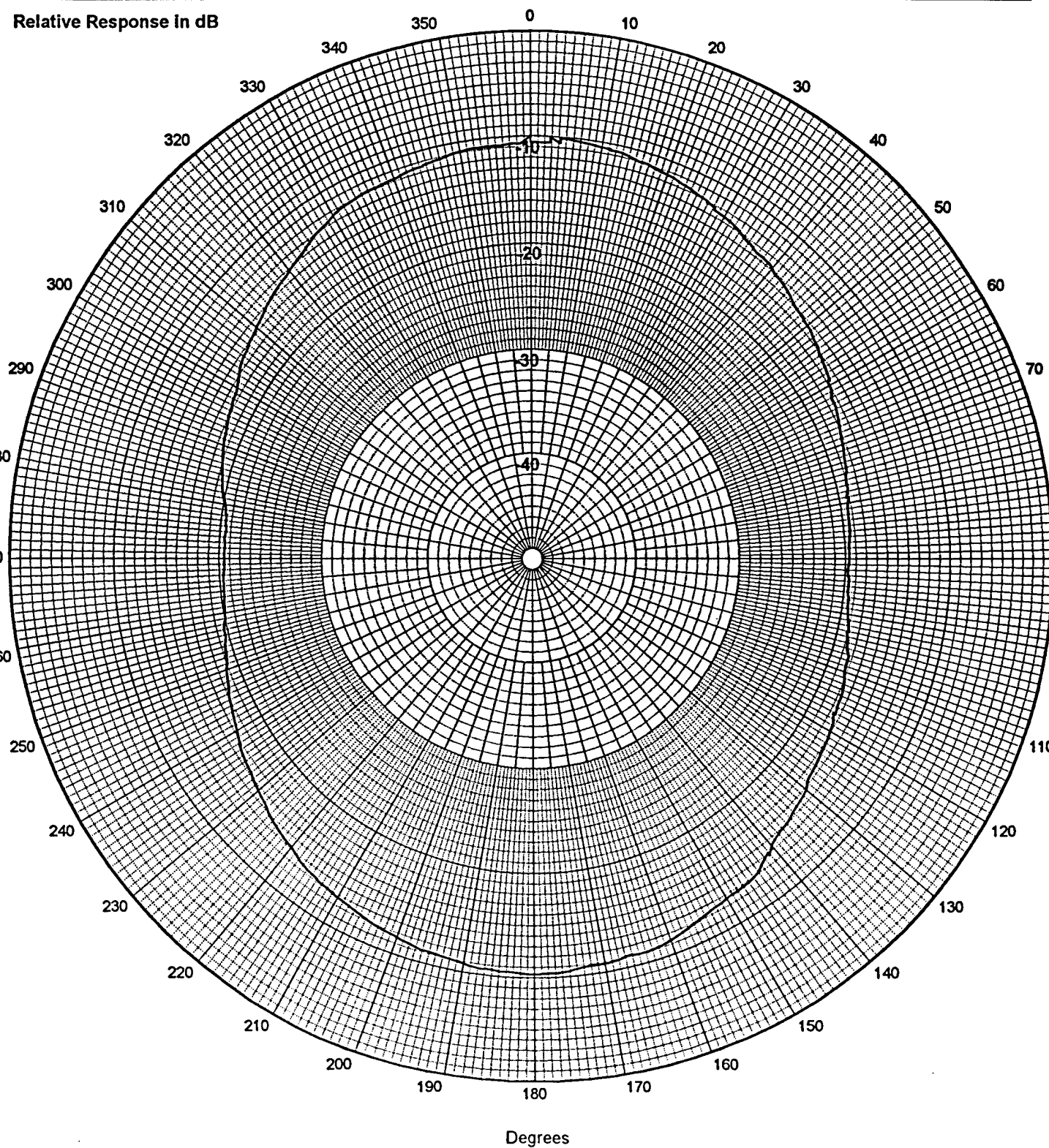
Piezocomposite Transducer Serial 10 - 57

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 5.0 kHz

Relative Response in dB



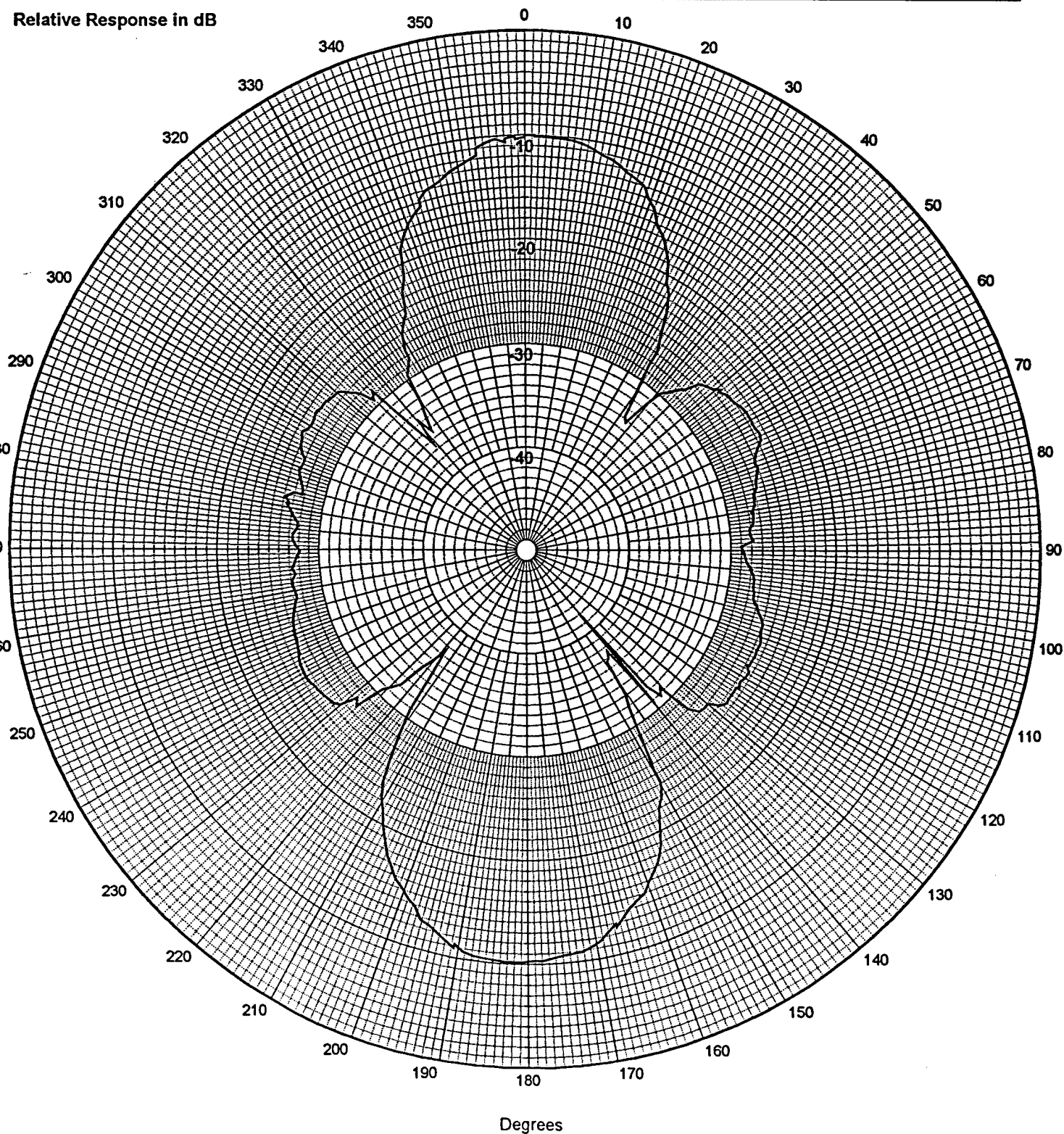
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-49  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 57  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 10 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

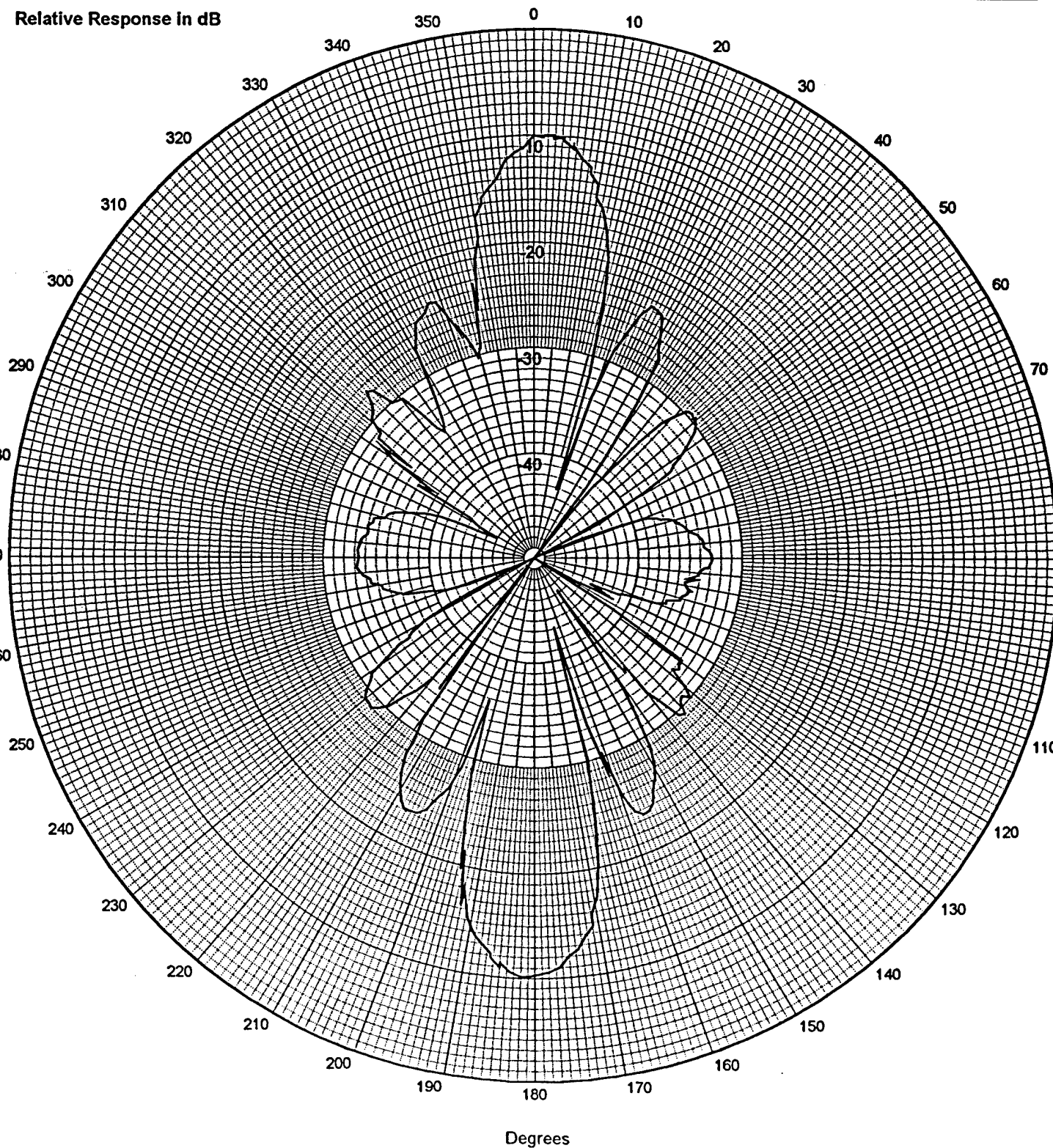
Piezocomposite Transducer Serial 10 - 57

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 20 kHz

Relative Response in dB



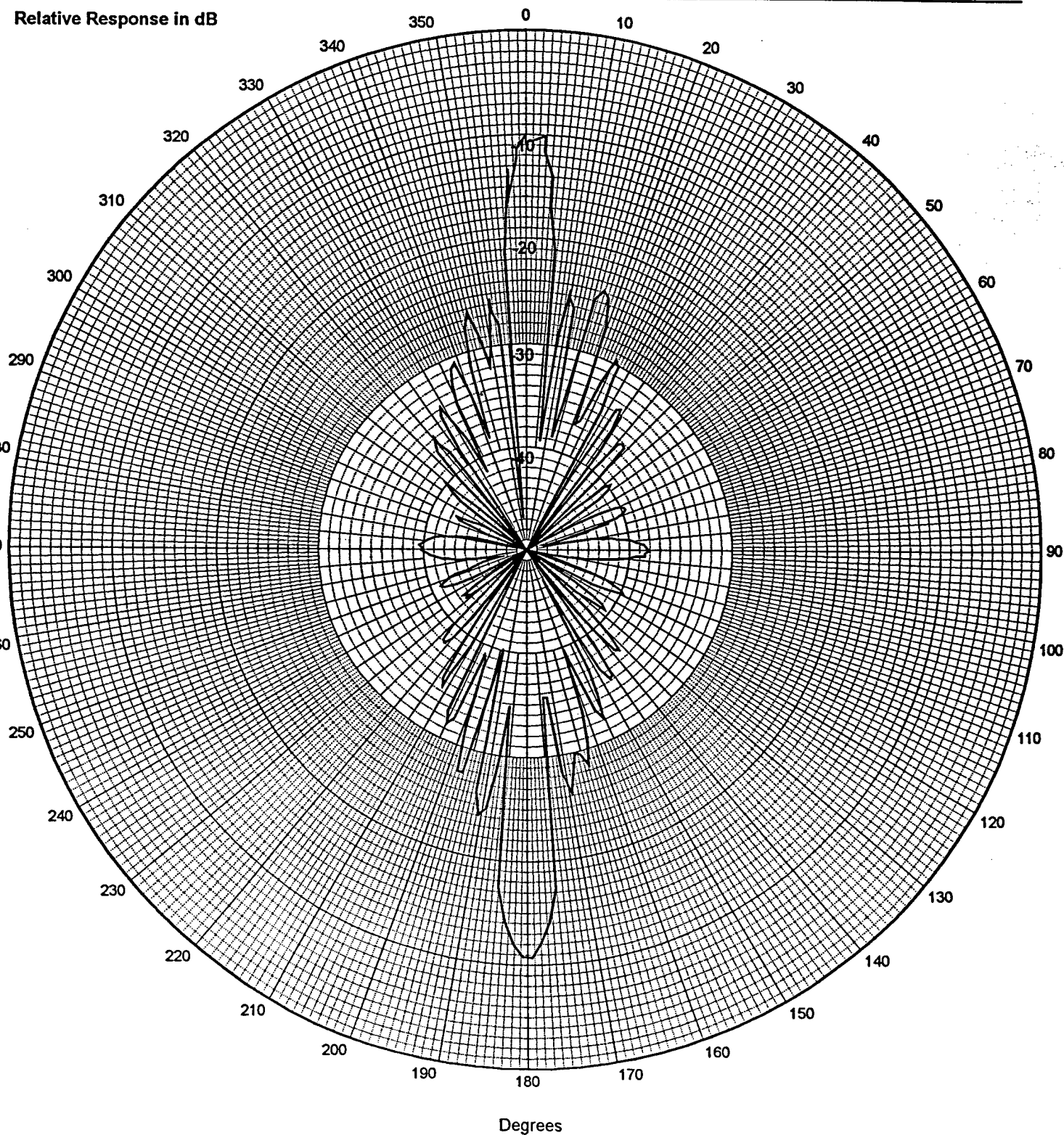
NAVAL UNDERSEA WARFARE CENTER  
UNDERWATER SOUND REFERENCE DETACHMENT  
P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-51  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 57  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 50 kHz

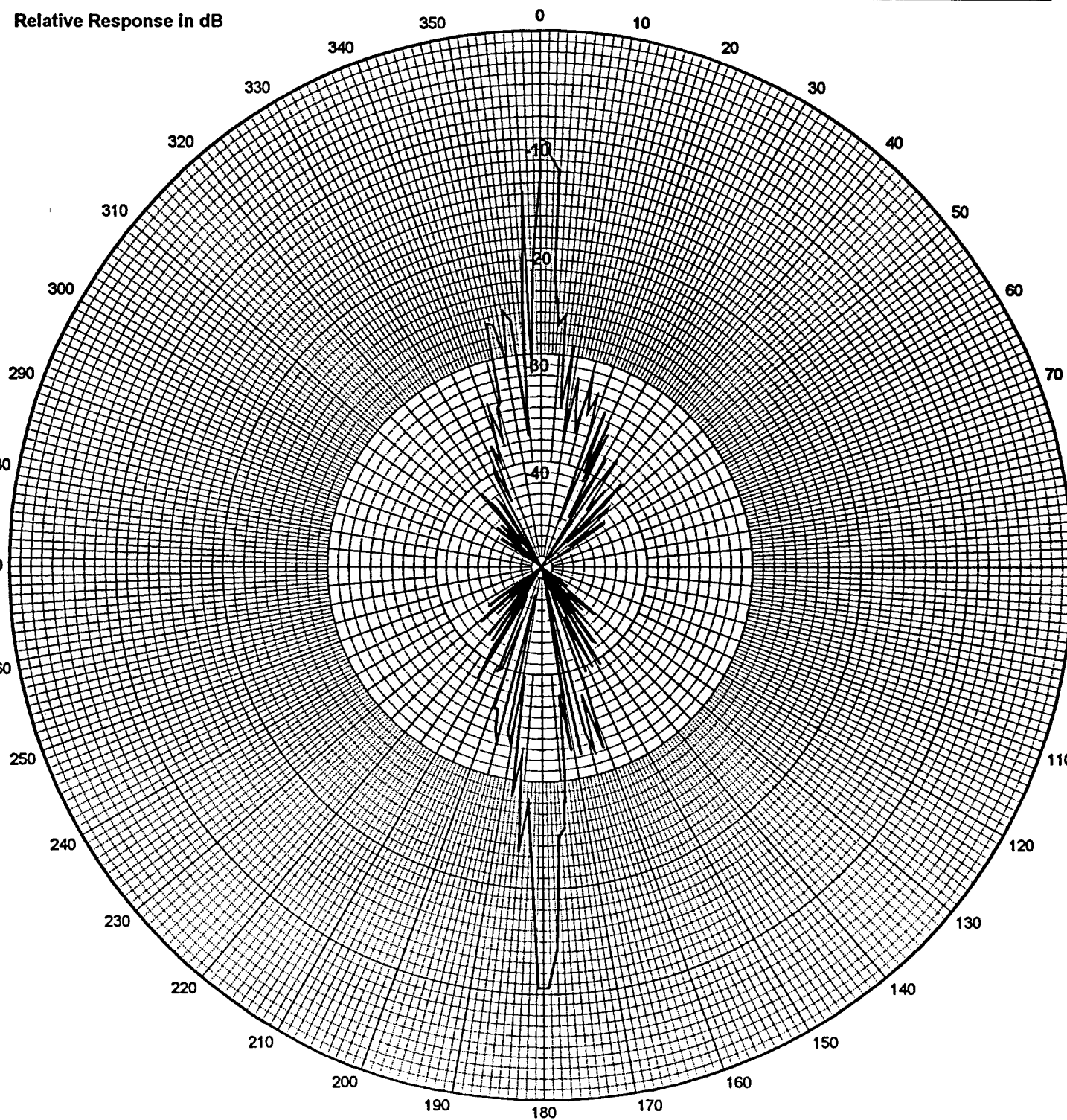
Relative Response in dB



## DIRECTIONAL RESPONSE

Piezocomposite Transducer Serial 10 - 57  
Depth: 3.9 m ( 38 kPa )  
Water Temp: 30° C  
Receive, XY Plane, 100 kHz

Relative Response in dB



Degrees

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P. O. BOX 568337, ORLANDO, FLORIDA 32856-8337

USRD NO: 0851-53  
LAKE FACILITY  
AUG 1996

## DIRECTIONAL RESPONSE

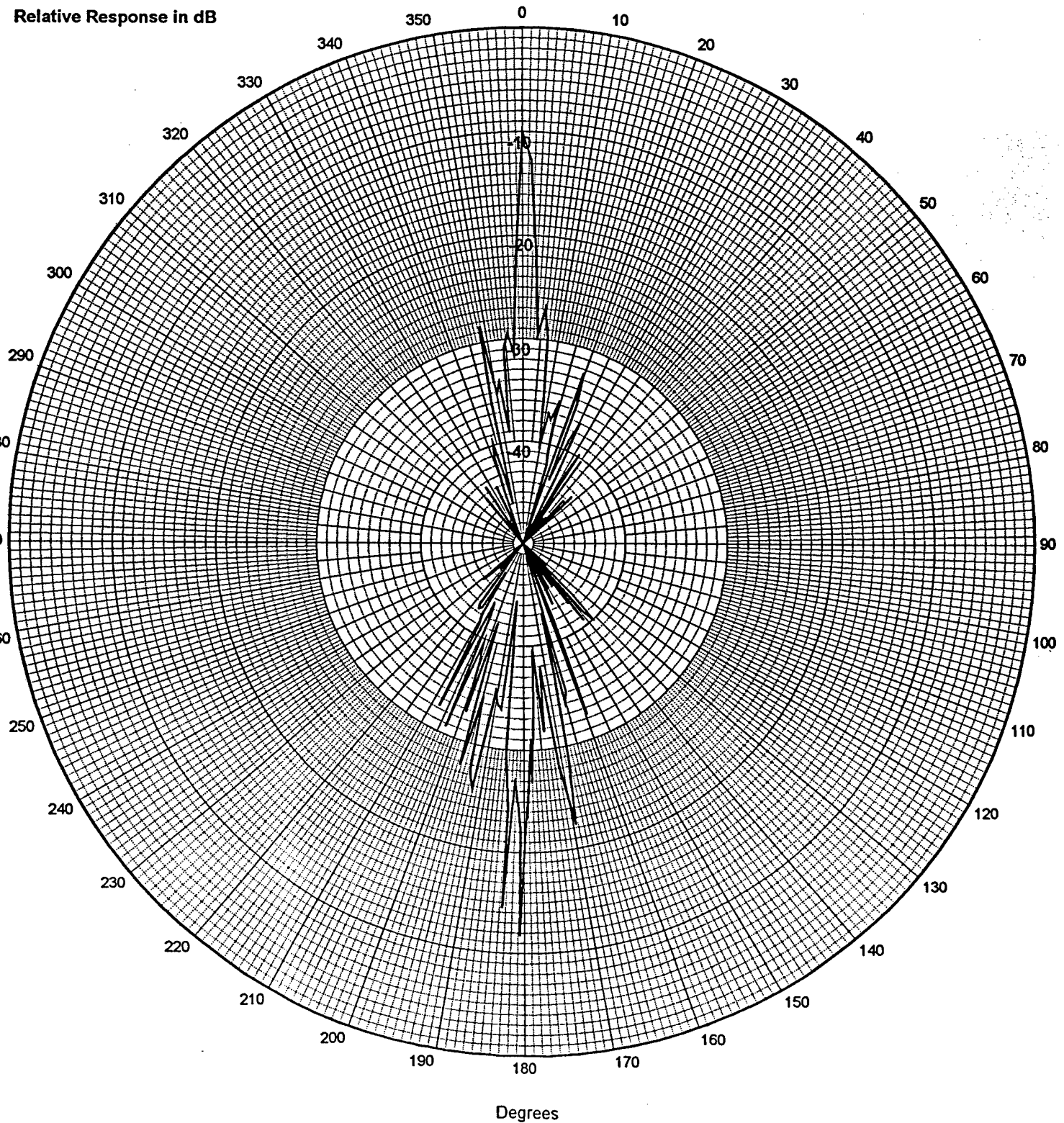
Piezocomposite Transducer Serial 10 - 57

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 200 kHz

Relative Response in dB





## DIRECTIONAL RESPONSE

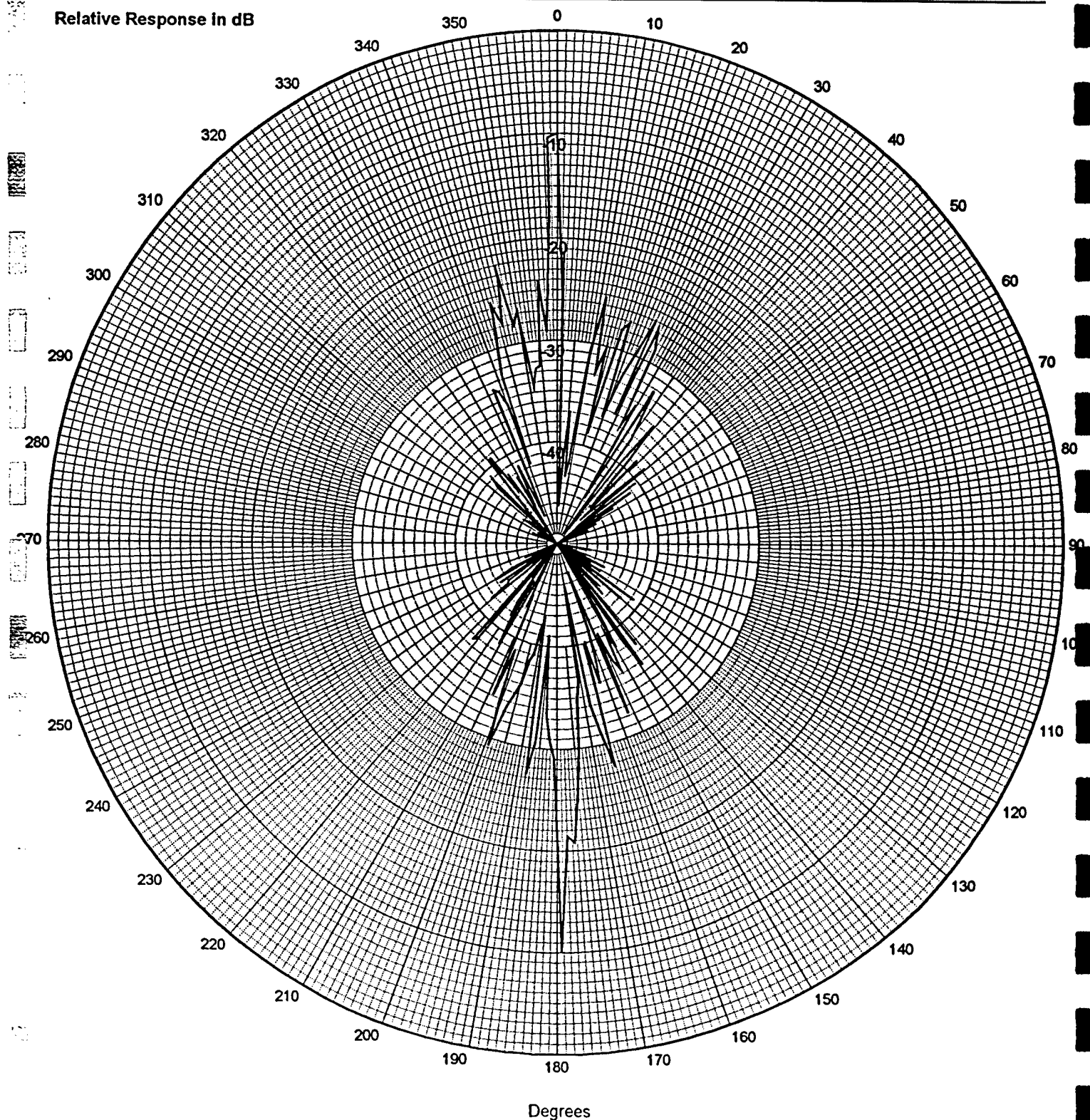
Piezocomposite Transducer Serial 10 - 57

Depth: 3.9 m ( 38 kPa )

Water Temp: 30° C

Receive, XY Plane, 300 kHz

Relative Response in dB



UNCLASSIFIED

NAVAL UNDERSEA WARFARE CENTER DIVISION  
UNDERWATER SOUND REFERENCE DETACHMENT  
PO BOX 568337, ORLANDO, FL 32856-8337

USRD DRAWING 62785  
(Revised 1 August 1996)

## COORDINATE SYSTEM FOR TRANSDUCER OR PANEL ORIENTATION

The left-handed coordinate system in the sketch below is affixed to the transducer or panel and moves with it, regardless of its physical position. The angle  $(\theta, \phi)$  denotes the direction of sound propagation. Measurements are made with sound propagated parallel to the positive X axis ( $\theta = 90^\circ$ ,  $\phi = 0^\circ$ ) unless otherwise specified.

For some measurements, the position of an auxiliary transducer may be specified in terms of cartesian coordinates X, Y, and Z.

Transducers and panels are oriented as follows

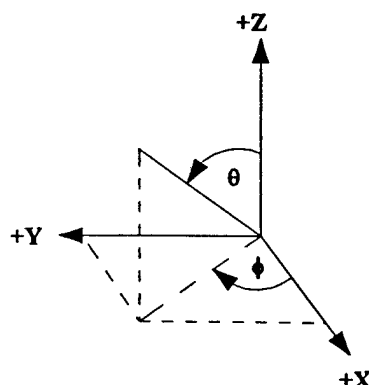
### ACOUSTIC SURFACE

### ORIENTATION

Cylinder	The cylindrical axis is the Z axis; a reference mark for the +Z direction and for another axis is specified.
Plane	The plane or piston face is in the YZ plane, with the X axis normal to the face at the geometric center. A reference mark in the YZ plane is specified.
Sphere	Points on the surface for any two of the three axes are specified.
Other	A sketch of non-conforming configurations is provided.

**Directional Response Patterns: Unless otherwise specified, the following apply**

SPECIFIED PLANE	AXIS OF ROTATION	POSITION OF AXES OR DIRECTIONS ON POLAR PLOTS				
		+ X AXIS	+Y AXIS	+Z AXIS	$\theta = 45^\circ$ $\phi = 90^\circ$	$\theta = 45^\circ$ $\phi = 270^\circ$
XY	Z	$0^\circ$	$90^\circ$ CW	Upward	_____	_____
XZ	Y	$0^\circ$	Downward	$90^\circ$ CW	_____	_____
YZ	X	Upward	$0^\circ$	$90^\circ$ CW	_____	_____
Roll	$\theta = 45^\circ$ $\phi = 270^\circ$	$0^\circ$	_____	_____	$90^\circ$ CW	Upward



Origin is at assumed acoustic  
center of transducer or panel

UNCLASSIFIED

# Appendix G

**EFFECTS OF TEMPERATURE AND PRESSURE ON  
THE ACOUSTICAL PROPERTIES OF  
LARGE 1-3 PIEZOCOMPOSITE PANELS**

(Final Report)

submitted to

Mr. Jan Lindberg  
Code 213  
Naval Undersea Warfare Center  
Newport, RI 02841-1708

Contract No. N66604-98-M-0722

Prepared By

Professor Robert Y. Ting, Ph.D.  
Department of Chemistry  
University of Central Florida  
P.O. Box 162366  
Orlando, FL 32816-2366

May 1998



## **I. INTRODUCTION**

In recent years there has been a steadily increasing interest in the development of so-called smart materials for various defense and industrial applications [1,2]. In the fall of 1994, ARPA launched its Smart Materials and Structures Program. As a part of this new initiative, injection-molded 1-3 piezocomposite materials [3] are, among others, selected as a candidate for smart materials study. Navy laboratories including NUWC-USRD and NRL together with the Materials Systems Incorporated (MSI) in Littleton, MA formed a team for the development of a high-performance, pressure-stable piezocomposite materials system for naval undersea applications.

The new class of piezoelectric composite materials was originally developed under Navy 6.1 and 6.2 sponsorship for large-area hydrophone applications on submersible platforms in order to improve the low-frequency submarine sonar capability. Generally, piezocomposites consist of a ceramic and a polymeric phase with a variety of connectivity designs [4] in order to improve its piezoelectric and electromechanical properties over those of conventional piezoelectric ceramics such as the PZT family [5]. In particular, these composites exhibit a much superior piezoelectric response in a hydrostatic mode. In terms of a figure of merit the  $(d \times g)$  product in hydrostatic mode could be two to three orders of magnitude greater than that for PZTs [6]. Furthermore, the new piezocomposites contain more than 50% volume fraction of polymeric materials. Therefore, its density is much less than that of PZT ceramics. In addition to being of a lower weight and mechanically flexible, the piezocomposites also offer the potential of being of much lower cost than piezoelectric ceramics, because it can be processed as large sheets by using the conventional rubber or plastic processing techniques.

Because of these distinctive advantages, piezocomposites were selected by ARPA for both sensor and actuator applications in large smart structures. In particular, ARPA was interested in

the injection-molded 1-3 piezocomposites developed by MSI under an earlier ONR SBIR contract in conjunction with NUWC-USRD. PZT-5H ceramic slurries were injection-molded into a preform containing thin ceramic rods aligned in the vertical direction. Polyurethane resins were then back filled as a matrix material to produce a composite tile having both the "1" connectivity for ceramic and "3" for the polymer phase, thus named "1-3" composites, (see schematic of Fig. 1). These tiles of the size of about 50 mm x 50 mm can then be used to assemble large flat panels of desired dimensions. It is anticipated that these piezocomposite panels can be used for both the detection of acoustical and vibrational signals and the actuation of a smart materials system for potential applications on submarine for vibration control.

## **II. BACKGROUND**

Under the sponsorship of ARPA in FY95 and 96, MSI standard SonoPanels were evaluated for their acoustical performance at NUWC-USRD Anechoic Tank Facility (ATF1) and Lake Facility. Both the ceramic phase and the polyurethane resin system then went through a parametric study subsequently in order to optimize the performance of the composite panels in the acoustical frequency range of interest. The final goal also includes the material component selection to achieve a smart materials candidate that is both stable with temperature and pressure. Furthermore, in order to simplify the material processing leading to additional cost reduction, a polymer composition was developed to enable one to eliminate the copper cover plate in the final 1-3 piezocomposite design. The evaluations of new panel samples up to 25.4 cm x 25.4 cm in size were completed at the end of FY96.

In FY97 it was planned to evaluate final panels of the dimensions of 183 cm x 183 cm x 2.54 cm thick. Funding difficulties and USRD closure forced a modification of that early plan.

Two 76 cm x 76 cm panels of different composite designs were prepared by MSI for acoustical evaluation in open lake and in anechoic tank ATF1. Both panels were scheduled for such tests prior to the ATF1 closure in July 1997. Pre- and post-"environmental" acoustical tests were also carried out at the Leesburg Lake Facility (LeeFac) in Bug Spring, FL, in order to determine if damages due to pressure and pressure-cycling ever occurred to the composite panels which were not evident to the naked eyes. The panels were subsequently returned to the supplier MSI. In this report, all the acoustical test data were reviewed and analyzed to determine the effects of temperature and pressure on the acoustical performance of these large 1-3 piezocomposite panels.

### **III. PIEZOCOMPOSITE PANELS**

Conventional 1-3 piezocomposite materials have typically been fabricated by using a dice-and-fill method, which is adequate for the preparation of small samples required in ultrasonic medical imaging applications [7]. However, this method is too costly to meet the need of large area coverage in Naval applications, and is difficult to maintain material uniformity in large sheets. Recently, the Office of Naval Research funded a number of new initiatives to explore alternative low-cost fabrication techniques for the manufacturing of large sheets of 1-3 piezocomposite materials. One of the more successful approaches is that of the Materials System Inc.(MSI, Littleton, MA), where an injection molding technique [3] is used to make 1-3 composites. The basic configuration of the MSI fabrication is a ceramic preform 50 x 50 mm<sup>2</sup> in size, containing a 19 x 19 array of 361 rods. Each rod is 1.1 mm in diameter and about 6.5 mm in height. The ceramic of present choice is the PZT-5H composition from Morgan Matroc Inc. Once properly characterized, ceramic powder is thoroughly mixed with a binder to form a viscous slurry. During the injection molding process, the slurry mixture is forced into a cooled mold to form a net shape

green part. This part is subsequently heated in air for the removal of the organic binder. Sintering then takes place at 1250°C for one hour in a controlled atmosphere to optimize the PZT piezoelectric properties. The preform is then contact poled under high electric field. Figure 2 shows the preform as fabricated by this technique. Individual preform parts are assembled to the size of a desirable transducer panel and encapsulated by using castable resins such as polyurethane or epoxy under applied pressure. The panel assembly is subsequently cured in a vacuum oven, cooled and finished before permanent electrodes are applied and wires attached. The final 1-3 piezocomposite panel contains approximately 15% volume fraction of PZT with a nominal dielectric constant of 480 and a density of 1.8 g/cm<sup>3</sup>. Presently MSI is marketing this material under the trade name "SonoPanel 5H".

Two 80 cm X 80 cm panels were assembled by using this technique, each having an active area of 76 cm X 76 cm. The first panel was that of a standard SonoPanel, containing copper cover-plates on each side of the PZT-5H preforms, and is named the "copper" panel in this report. The PZT contain of this panel was 15%, and the encapsulant was a Shore A60 urethane with 40% microvoids. Its capacitance measured at 1 kHz was 364 nF.

One recent focus in this ARPA program was to investigate other possible means for stiffening the 1-3 piezocomposite panel so that the thin pc-board cover-plate could be eliminated for further cost reduction. An alternative design would be to replace the existing matrix with a higher modulus polymer, so the stiff matrix itself can be counted on for adequate stiffening. In addition, for improving the acoustic drive property of the 1-3 panels, it would be desirable to increase the ceramic volume fraction of the composite. Modified SonoPanels were therefore fabricated. The second panel in this test series employed a stiffer polyurethane resin called H566 having a Shore A80 hardness reading when fully cured. The PZT-5H contain was increased to



25%<sup>Vol</sup> Without the cover-plate attachment, a silver epoxy mono-electrode layer was applied. This second panel is therefore named the "silver" panel in the report. The capacitance at 1 kHz was 499 nF. The impedance curves for the two panels are shown in Fig. 3a and 3b. A thickness resonance for the copper panel appeared at 220 kHz. For the silver panel, due to interfering lateral modes the thickness mode resonance was not as distinct. A mode at about 162 kHz was seen. These different modes in the panels will be discussed later in the report.

#### IV. RESULTS AND DISCUSSION

##### RECEIVING CHARACTERISTICS

Before the panels were exposed to temperature and pressure cycles in the ATF, they were tested at the LeeFac open water in order to establish their basic acoustical performance. Fig. 4 shows the free field receiving sensitivity (FFVS) [8] of the copper panel (Standard SonoPanel) from 100 to 200,000 Hz at various orientations. It was shown that by turning either side of the panel toward the acoustic projector the receiving characteristics were the same. At the end-fire position, the first null appeared at 2 kHz and was about 32 dB down from a low-frequency FFVS of -180 dB re 1 v per uPa. For the zero orientation FFVS, two separate peaks appeared at 65 kHz and 105 kHz, respectively, representing the inter-rod resonances of the composite material as previously determined. These modes were not as distinct in the silver panel (modified SonoPanel). Fig. 5 also shows that the FFVS of this second panel was not constant as in Fig. 4. A strong low-frequency broad peak at about 500 Hz appeared, which is believed to be due to the in-plane flexing of the panel as a whole since this panel was not stiffened with a cover plate as in the copper panel. Once the panels were mounted in the ATF, because of the size limit of the tank the acoustical properties of the panels were expected to be different. Fig. 6 shows that the FFVS

over the range of 2 to 200 kHz appeared to drop off at a lower frequency than in open water. Under various levels of hydrostatic pressure the FFVS of the copper panel improved slightly. This is well known as a peculiar property of the microvoided urethane resins used in this configuration. At 500 psi, a deep hole began to develop around 16 kHz and the FFVS was decreased by about 15 dB. The two inter-pillar modes were still evident, but their structures were somewhat distorted by pressure. Fig. 7 shows that at 3 degrees C the copper panel suffered its most loss of FFVS at 1,000 psi. After this high pressure exposure, the FFVS did not recover when the pressure was set back to the ambient level, but lost about 3 dB. Once the low temperature and high pressure combination was present, it caused additional modes in the panel as seen in this figure. The selection of the soft-8 resin for the modified panel was because of its pressure stability. Indeed, the results shown in the FFVS of Figs 8 and 9 confirmed this choice. Fig. 9 indicates that the 3-deg C FFVS was essentially pressure independent from ambient to 1,000 psi. Once the ATF pressure tests were completed, the panels were returned to LeeFac for post-ATF check. Fig. 10 shows the FFVS of the copper panel, both pre- and post-ATF results. The "damage" caused by pressure cycling is clearly seen in the copper panel, whereas the silver panel seemed to have survived well (Fig. 11). Since the silver panel was not stiffened and a low frequency peak showed the in-plane flexing mode, it was attempted to stiffen this panel with a 3/8-inch thick (0.93 cm) steel plate with the hope that this would remove the low frequency mode and improve the FFVS. Fig. 12 shows this result, clearly the measure of a simple clamping was not useful. Not only it did not affect the 500 Hz peak, but caused other complications at higher frequencies. It is believed that, if time had allowed, one should have carefully calculated the required stiffening and completely bonded the panel to a stiffening plate with adhesives so that the low frequency flexing could be properly eliminated.

## TRANSMITTING CHARACTERISTICS

Fig. 13 shows the transmitting voltage response (TVR) [8] of the copper panel measured in open water at LeeFac from 100 to 200,000 Hz. It was unfortunate that the test frequency was not extended further to cover the 220 kHz thickness mode. The inter-pillar modes at 65 and 100+ kHz were evident. Another mode at 90 kHz has always been in question in the course of this investigation, since finite-element modeling did not show this mode and thus its origin could not be identified. The primary thickness mode resonance for the standard SonoPanel was calculated to be at 230 kHz, which was in reasonable agreement with the impedance measurement. The inter-pillar modes, of course, depend greatly on the geometrical design of the rod-to-rod spacing and the aspect ratio of individual rods. The increase in TVR with frequency followed the normal 12 dB per octave variation below 10 kHz, indicating that the overall panel displacement in this case is somewhat similar to that of an idealized point source. As the TVR peaks were approached, this slope increased slightly. For the silver panel which contained 25% volume fraction of PZT5H in comparison to the 15% ceramic in the standard copper panel, it was surprising to find that the TVR was about 2 dB less than that for the standard panel (Fig. 14). Considering the non-uniform FFVS of the modified panel in Fig. 5, one should perhaps not be surprised. In this panel, for the lack of sufficient stiffness a variety of modes from the in-plane vibrational motion could have taken the energy away from the plane wave projection of the panel and caused this reduction in TVR. The resonance structure in the TVR of the silver panel was also somewhat different from that in the copper panel. The silver panel contained diamond-shaped rod at a closer spacing in order to achieve the desired 25% volume fraction of the ceramic. It is believed that these measures could have contributed to the changes in the resonance characteristics of the panel. The severe adverse effect of pressure on the TVR of copper panel is

shown in Fig. 15. A temporary improvement was seen at 500 psi, as known before with this matrix resin. Fig. 16 shows that at 3-deg C the 1,000 psi pressure caused the panel to lose its TVR by as much as 20+ dB. After this pressure the panel did not fully recover. At the maximum peak the TVR was reduced by about 5 dB. When the panel was returned to LeeFac for post-pressure check, Fig. 13 shows that the loss of TVR at low frequency and the shifting toward high frequencies. Figs 17 and 18 show the pressure stability of the TVR of the silver panel at both 22 and 3-deg C. The peak at 140 kHz may be identified with that seen in the impedance measurement. The resonance structure was clearly much well behaved than that in the copper panel under pressure.

Directivity patterns for the transmitting case were obtained for both panels at 10, 20, 40 and 100 kHz in the ATF. For clarity, only the 10 kHz beam patterns will be shown here for comparison to illustrate the pressure and temperature effects. Fig. 19 gives the pattern for the copper panel at room temperature. The 3-dB down point showed a beam-width of 10 degrees. The first side lobe was down 7 dB from the main beam. Under 1,000 psi, the pattern of the main beam remained nearly the same, as seen in Fig. 20. The beam width was the same, but the first lobe was down 11 dB. This is somewhat surprising in view of the severe effect hydrostatic pressure had on the TVR. The most striking feature of the pattern may be the growth of the side lobes between 240 to 290 degrees under pressure. At 3-deg C the pressure effect on directivity patterns was a total alteration of the beam structure, as seen in Figs 21 and 22. At ambient pressure the beam pattern was still the same as at 22-deg C. Once a 1,000 psi pressure was applied, the familiar pattern, which was in general agreement with the theoretical prediction [8], was totally lost. When returning to ambient, the pattern shown in Fig. 23 seemed to be restored except a little loss of the strength of the main lobe.



Fig.s 24 and 25 show the directivity patterns of the silver panel at 10 kHz and 22 deg C. These represent the best patterns seen in ATF in agreement with the theory. The effect of pressure seemed again to be minimal for this panel. At the low temperature of 3 degrees C, Fig.s 26 - 28 show that the pattern was maintained at 1,000 psi with only a slight modification at both end-fire positions.

Fig. 29 shows the 10 kHz directivity pattern of the copper panel obtained in open water at LeeFac. The good quality of this pattern in comparison with those obtained in the ATF clearly illustrates the size limit of the anechoic tank for testing such large panels. In the open water, the distance between the projector and the panel was 8 meters for FFVS measurement from 100 to 10,000 Hz and 16.75 meters from 10 kHz up [9]. For the TVR case the hydrophones were placed 5 meters away from the panel for the low frequency range (100 to 10,000 Hz) and 14.75 meters for 10 kHz and up [10]. However, in the ATF the separation between the test panel and the acoustical transducers was only 2 meters. Fig.s 29 and 30 show that after ATF pressurization the directivity pattern of the copper panel was nearly retained at 10 kHz, except slight deterioration of the side lobes. Fig.s 31 and 32 show the pre- and post-ATF directivity patterns of the silver panel, a near textbook pattern was given and not affected by pressure cycling up to 1,000 psi. The 10-degree beam width was obtained. The first side lobe was 13 dB down and the first null was 28 dB deep. If one intends to limit the application of this panel to high frequencies, then the low frequency in-plane flexing would not be of concern. Its good performance at high frequencies may imply that simple finite-element modeling technique should enable one to predict its characteristics in a more complicated structural configuration.

## V. CONCLUSION

Two 76 cm x 76 cm piezocomposite panels of the 1-3 connectivity pattern were evaluated for their underwater acoustical properties under various levels of hydrostatic pressure at different temperatures. The first panel was of the same configuration as the standard MSI SonoPanel. This panel showed a pressure dependence on all receiving and transmitting characteristics, more degradation seen at low temperature than at room temperature. The second panel contained a stiff polyurethane matrix resin with no cover plates. The ceramic volume percentage was increased from the 15% for the standard SonoPanel to 25% by using a diamond shaped ceramic rod configuration for closer packing. The polyurethane resin was selected based on a series of parametric study, in which this specific resin showed no pressure dependence in a modified 1-3 piezocomposite panel. This pressure stability was confirmed in the current large-panel tests for this modified panel. Without cover plate, however, the resin did not provide sufficient stiffening, and low-frequency resonance relating to the in-plane flexural motion of the panel was evident. At higher frequencies, the panel behaved well acoustically as expected. In general, these panels could provide a free-field voltage sensitivity of about -185 dB re 1 v per uPa, constant from about 800 Hz to 30 kHz. They could also deliver in active mode a transmitting voltage response of 190 dB re 1 uPa at resonance around 100 kHz. At low frequencies, the rise of the transmitting voltage response with frequency is approximately 12 dB per octave. High drive properties of the panels have not been studied. The actual source level potential of these large piezocomposite panels remains to be investigated. In summary, the results presented in this research effort show that piezoelectric 1-3 composite materials are potentially useful materials for sensor and actuator applications in underwater smart skin designs.

## REFERENCES

- [1] R. A. Burdisso and C. R. Fuller, J. Acoust. Soc. Amer. 94, Pt. 2, 1816 (1993)
- [2] D. Damjanovic and R. E. Newnham, J. Intell. Mater. Syst. Struct. 3, 190 (1992)
- [3] R. L. Gentilman, D. F. Fiore, H. T. Pham, W. Serwatka, B. Pazol, C. Near and L. J. Bowen, "1-3 piezocomposite smart panels for active surface control," Paper No. 2721-27 in SPIE Symp. Industrial and Commercial Applications of Smart Structures Technologies, SPIE Proc. Vol. 2721, 27-29 Feb 1996, San Diego, CA
- [4] R. E. Newnham, L. J. Bowen, K. A. Klicker and L. E. Cross, "Composite Transducers," Materials in Engineering, 2, 93 (1986)
- [5] B. Jaffe, W. R. Cook and H. Jaffe, Piezoelectric Ceramics, Academic Press, New York (1971)
- [6] R. Y. Ting, "Evaluation of new piezoelectric composite materials for hydrophone applications," Ferroelectrics, 67, 143 (1986)
- [7] W. A. Smith, A. Shaulov and B. M. Singer, "Properties of composite piezoelectric materials for ultrasonic transducers," Proceeding IEEE Ultrasonic Symposium, Vol. 2, 539 (1984)
- [8] R. L. Bobber, Underwater Electroacoustic Measurements, Naval Research Laboratory, Wash. DC, July 1970.
- [9] "Test distances for frequency response of circular plates", USRL Report No. 15697 (1958)
- [10] "Test distances for frequency response of uniform line", USRL Report No. 15699 (1959)

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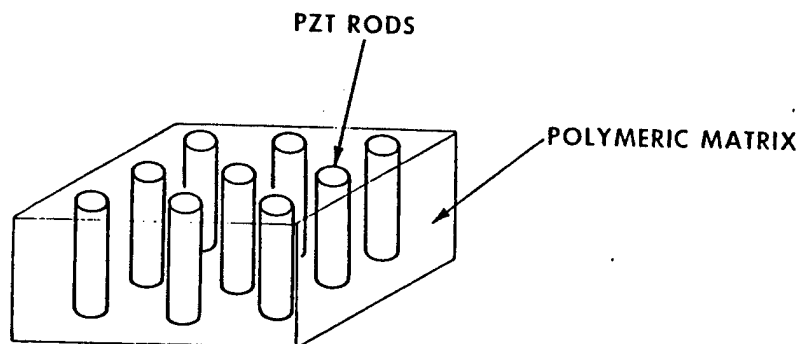


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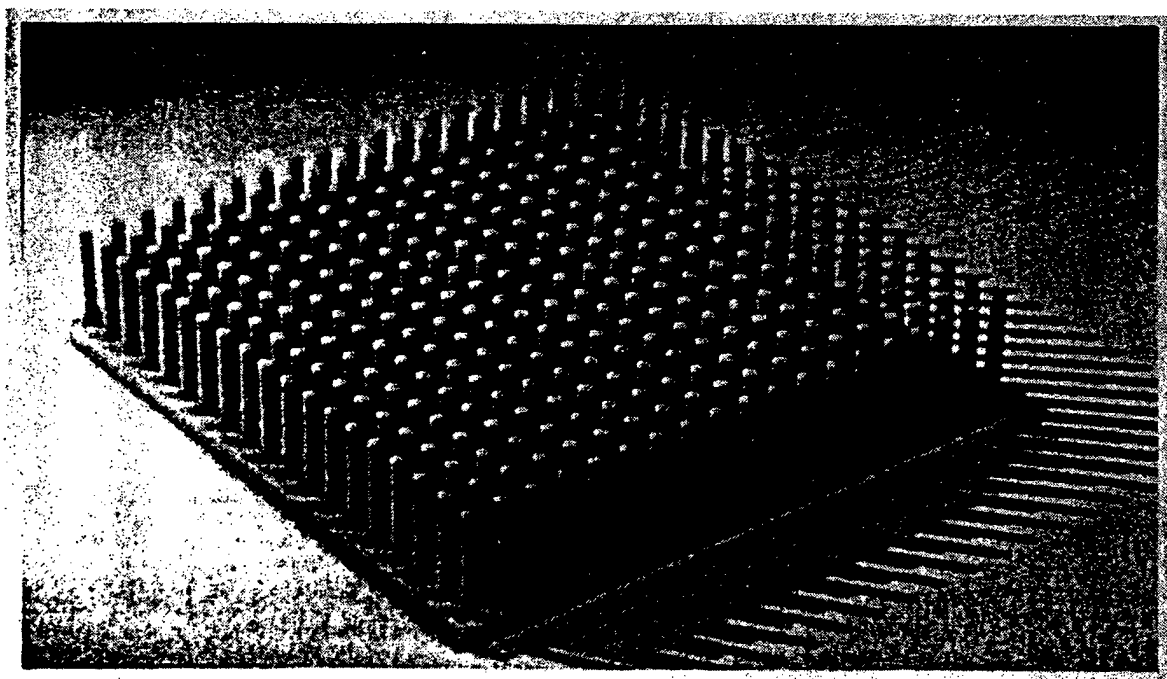


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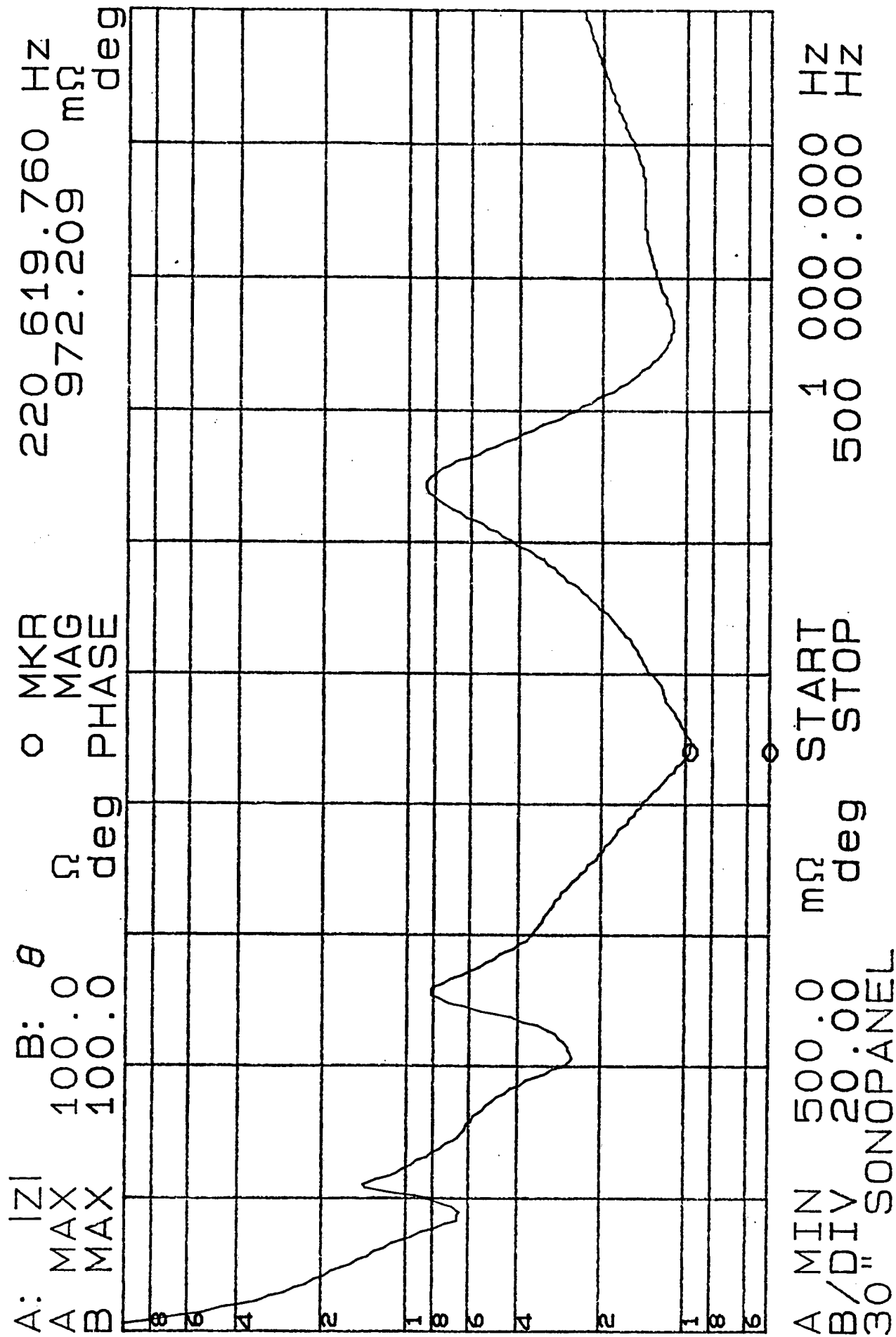


Figure 3a



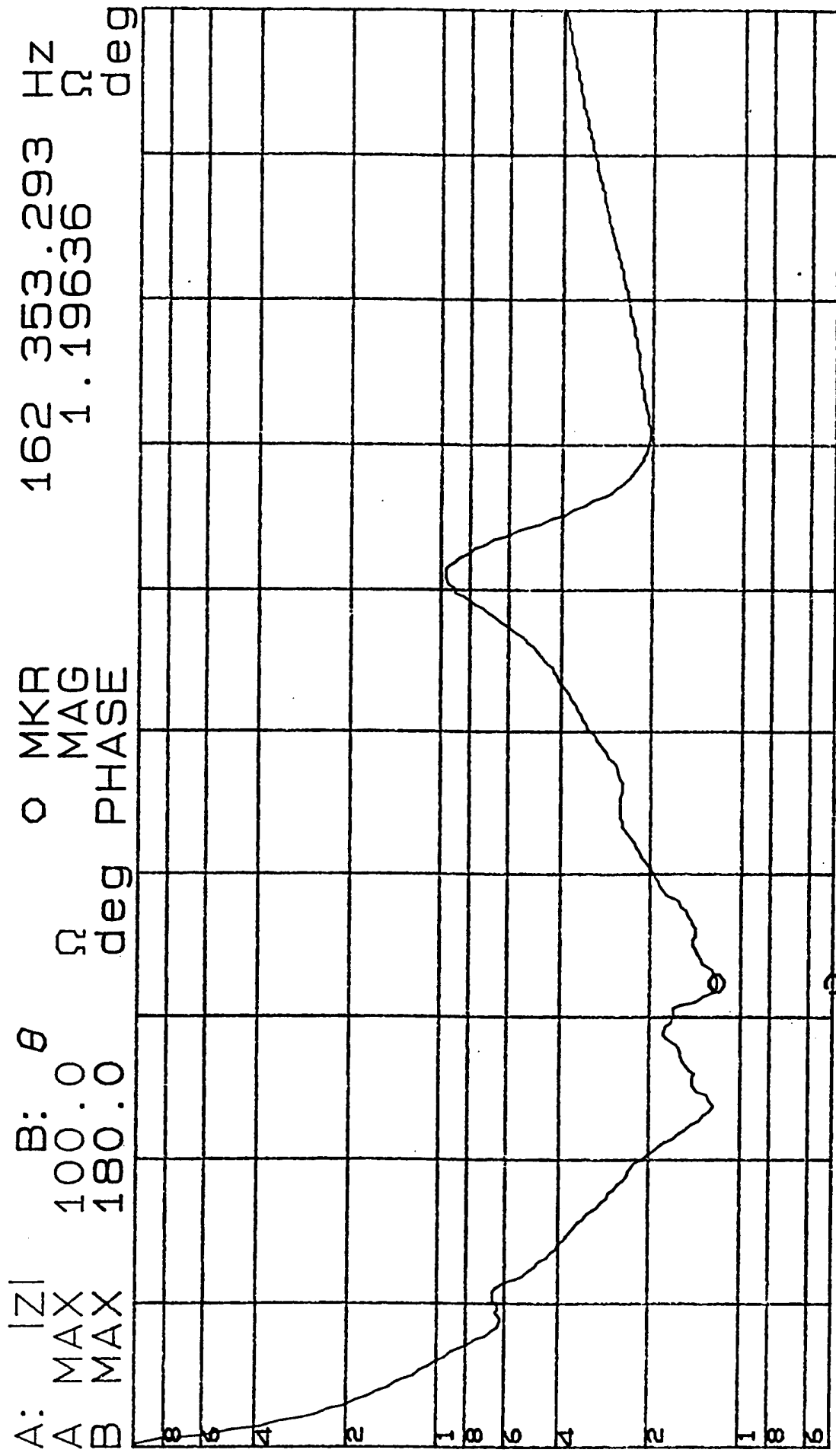


Figure 3b

22 °C 14.3 m (140 kPa)

—  $\theta = 90^\circ ; \phi = 0^\circ$   
- - -  $\theta = 90^\circ ; \phi = 180^\circ$   
.....  $\theta = 90^\circ ; \phi = 270^\circ$

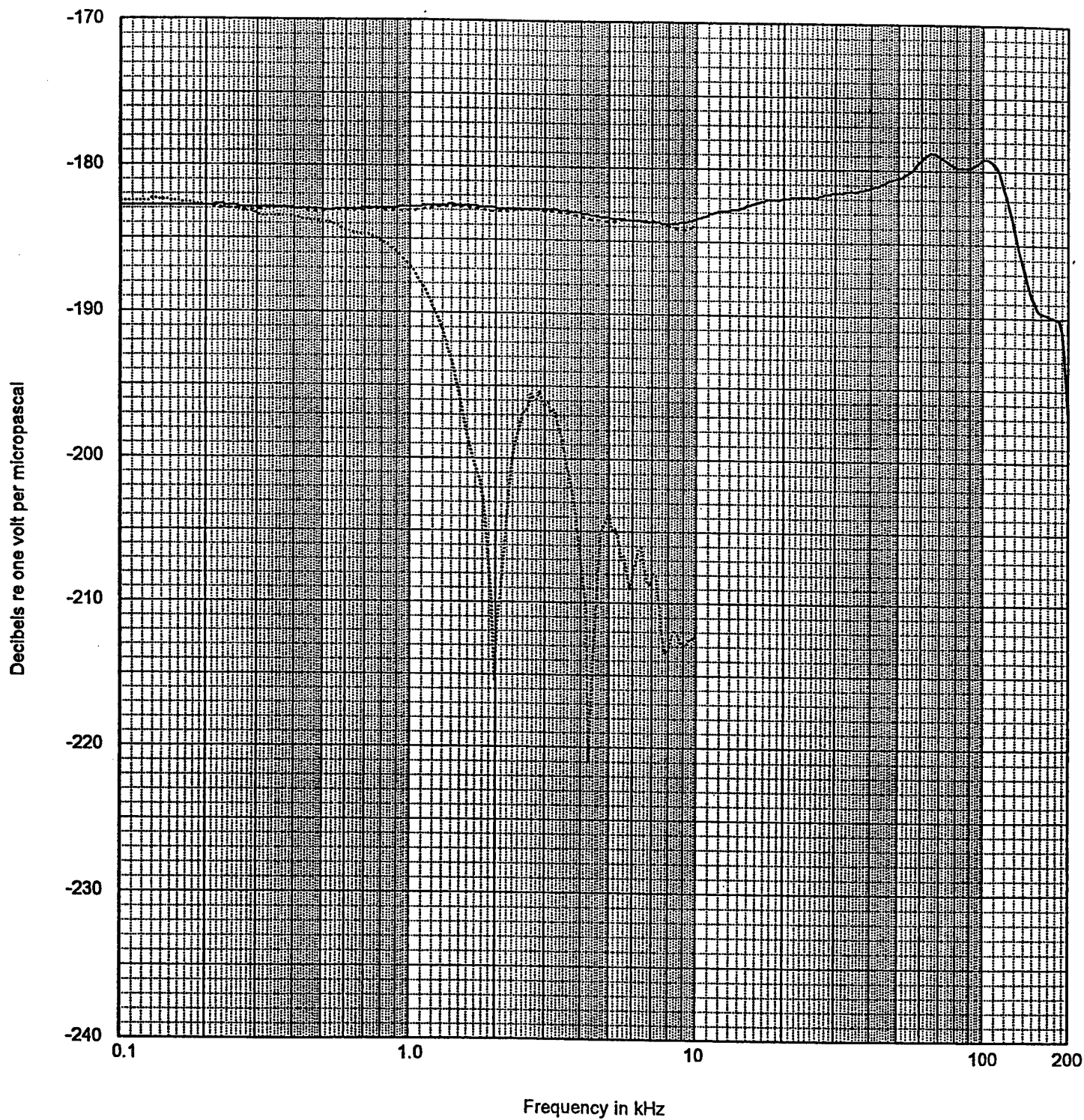


Fig. 4: Free field voltage sensitivity of the copper panel at different orientations measured in open water at LeeFac.

22 ° C 14.3 m (140 kPa)

—  $\theta = 90^\circ ; \phi = 0^\circ$

- - -  $\theta = 90^\circ ; \phi = 180^\circ$

.....  $\theta = 90^\circ ; \phi = 270^\circ$

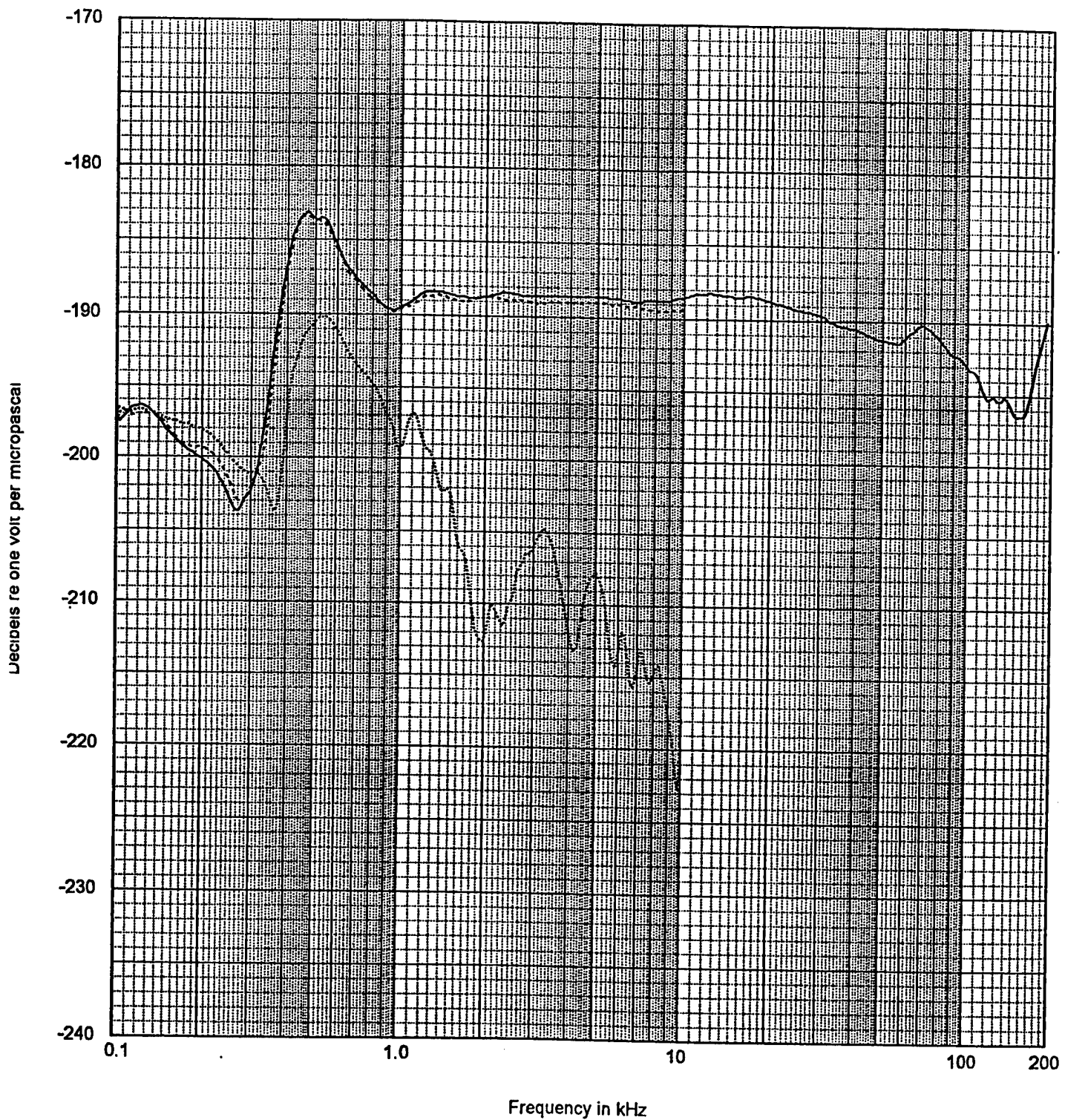


Fig. 5: Free field voltage sensitivity of the silver panel tested in open water for low frequency extension at LeeFac.

Water Temp: 22° C

— 16 kPa ( 1.6 m )  
- - - 689 kPa ( 70.3 m )  
- · - · - 3450 kPa ( 352.0 m )  
- - - 16 kPa ( 1.6 m ) After Pressure

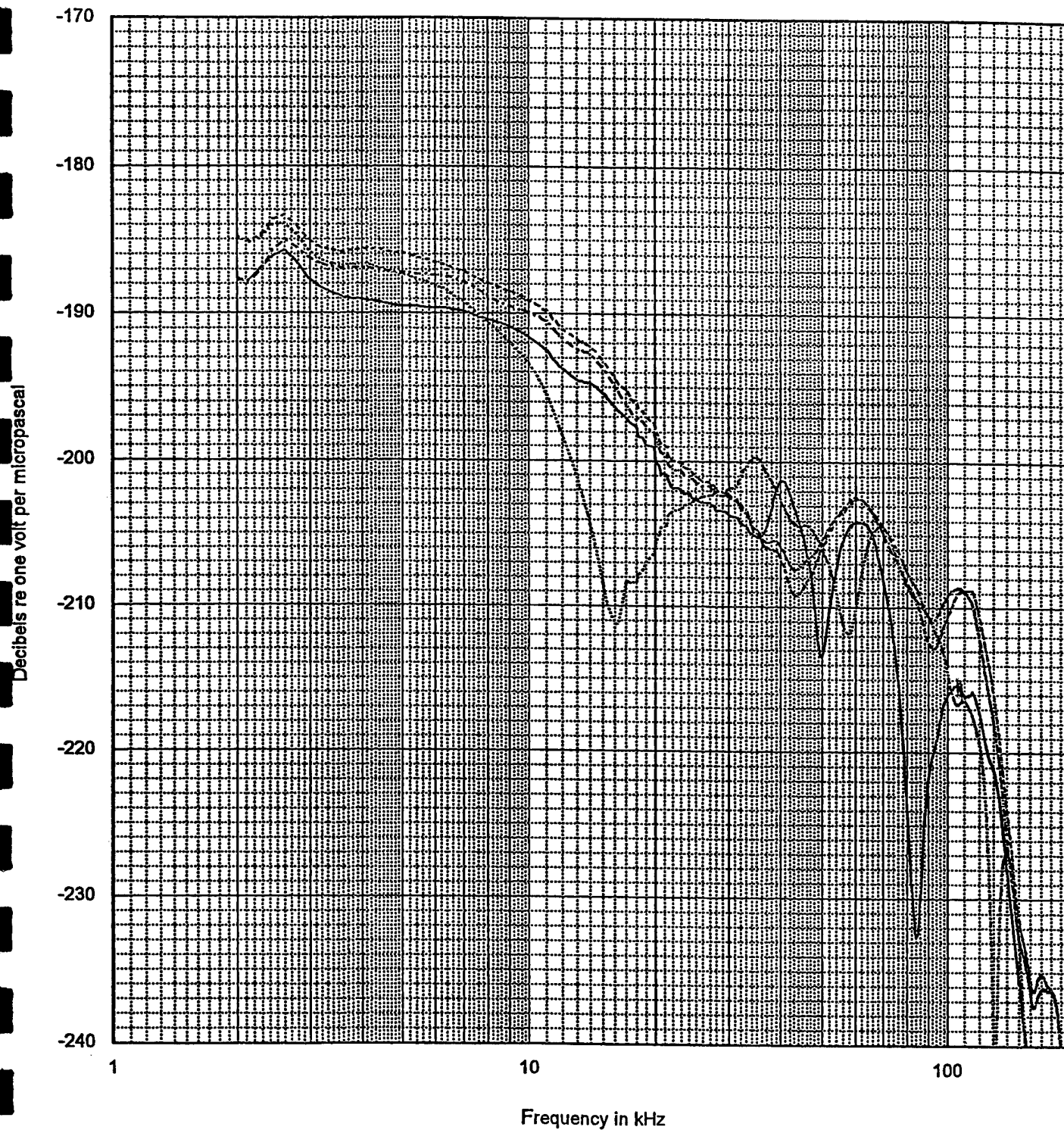


Fig. 6: Free field voltage sensitivity of the copper panel as a function of pressure at 22-deg C.



Water Temp: 3° C

—— 16 kPa ( 1.6 m )  
----- 689 kPa ( 70.3 m )  
..... 6890 kPa ( 703.0 m )  
- - - - 16 kPa ( 1.6 m ) After Pressure

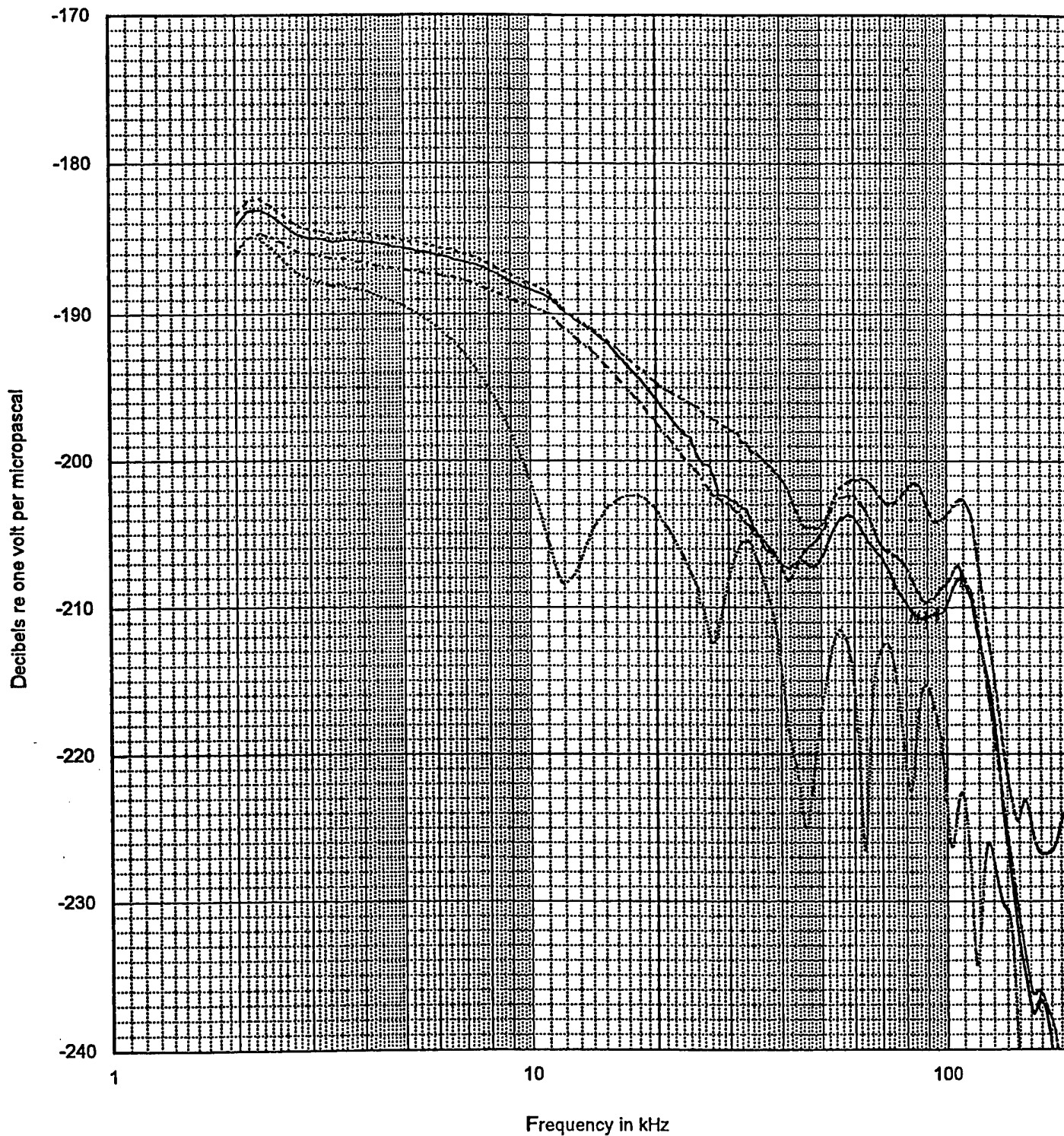


Fig. 7: Free field voltage sensitivity of the copper panel as a function of pressure at 3-deg C.



Water Temp: 22° C

— 16 kPa ( 1.6 m )  
- - - 689 kPa ( 70.3 m )  
..... 3450 kPa ( 352.0 m )  
- . - . 6890 kPa ( 703.0 m )  
- - - 16 kPa ( 1.6 m ) After Pressure

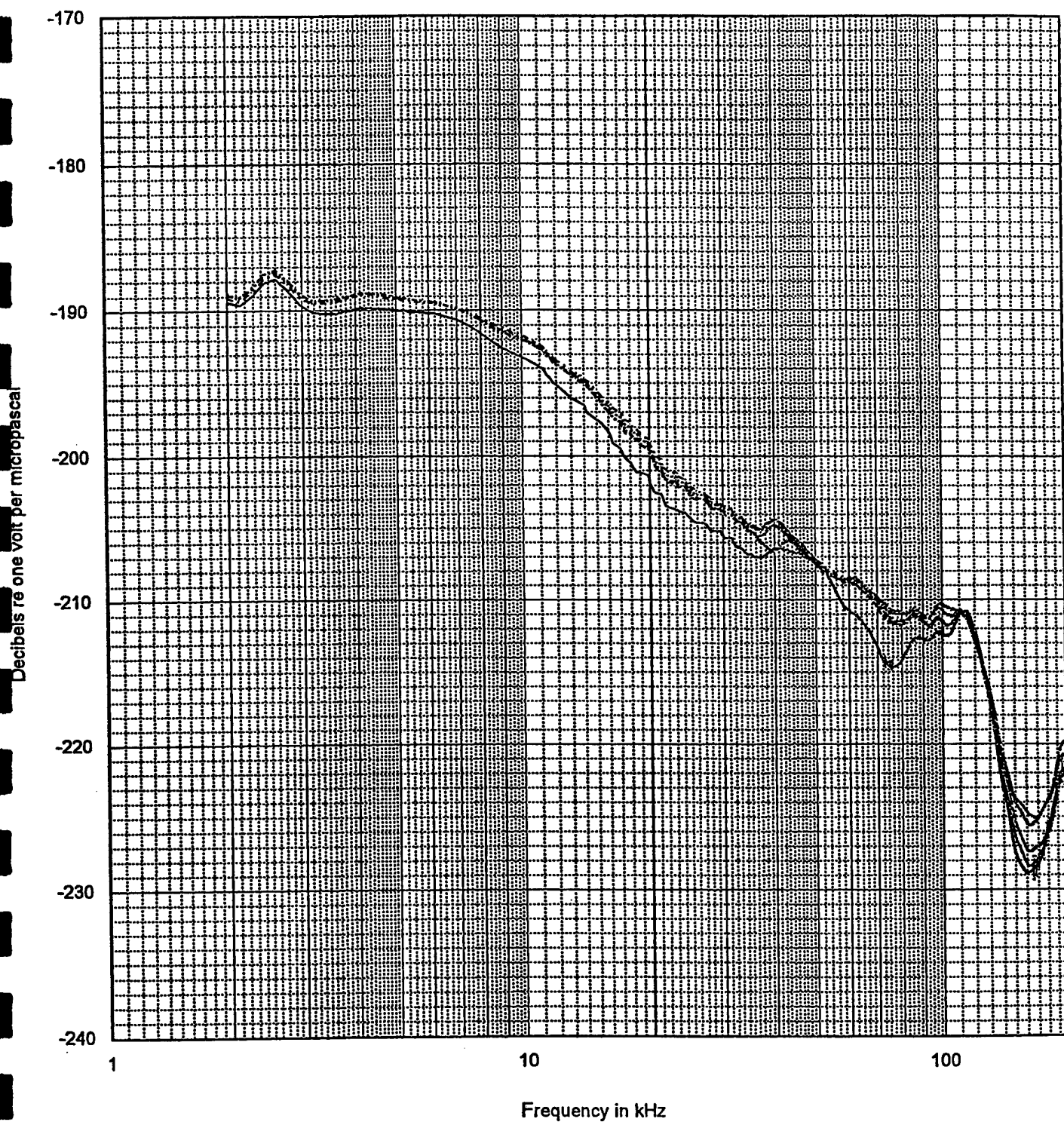


Fig. 8: Free field voltage sensitivity of the silver panel as a function of pressure at 22-deg C.

Water Temp: 3° C

———— 689 kPa ( 70.3 m )  
----- 3450 kPa ( 352.0 m )  
..... 6890 kPa ( 703.0 m )  
- - - - - 16 kPa ( 1.6 m ) After Pressure

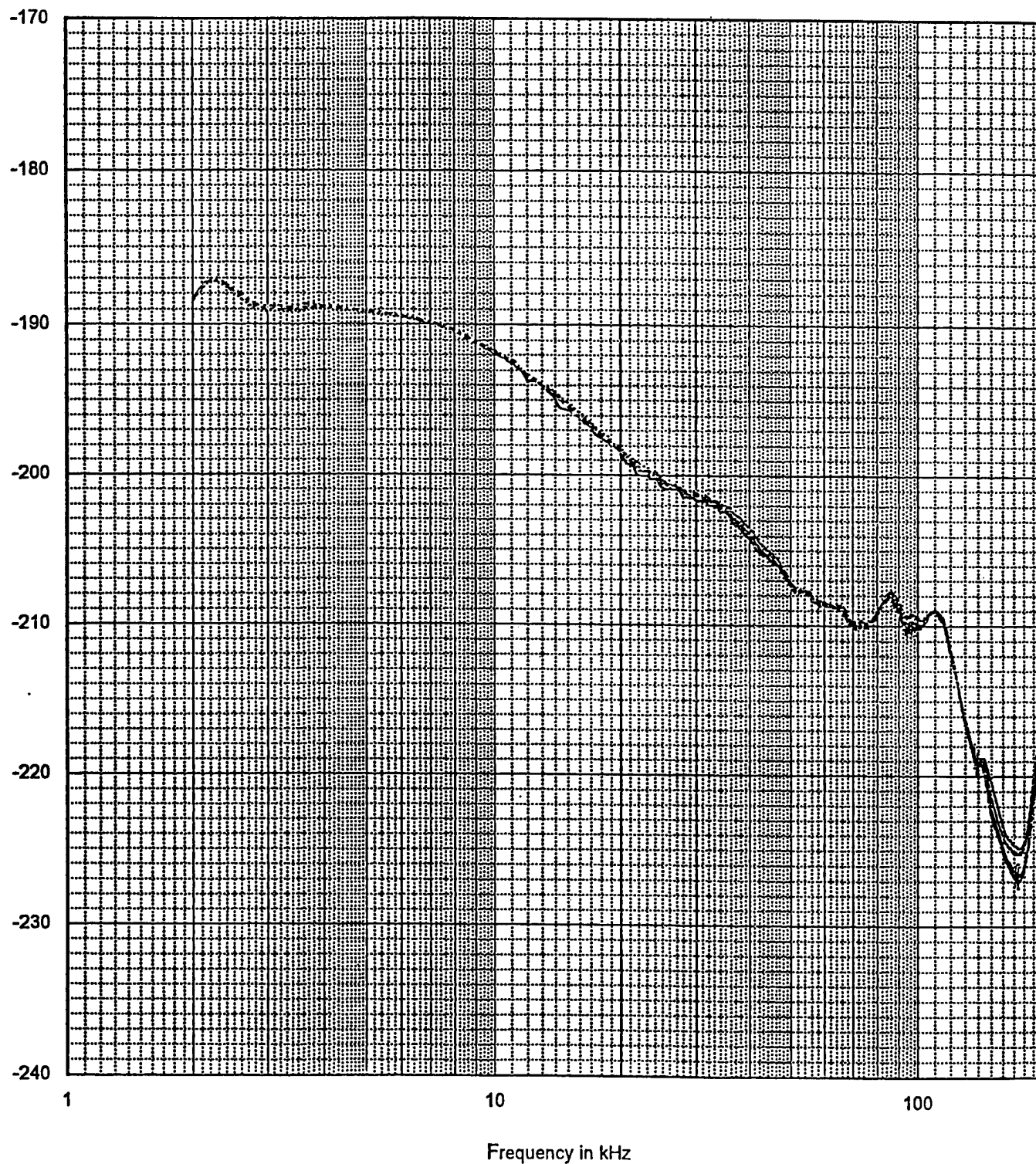


Fig. 9: Free field voltage sensitivity of the silver panel as a function of pressure at 3-deg C.

22 °C 14.3 m (140 kPa)

— Pre ATF measurements  
- - - Post ATF measurements

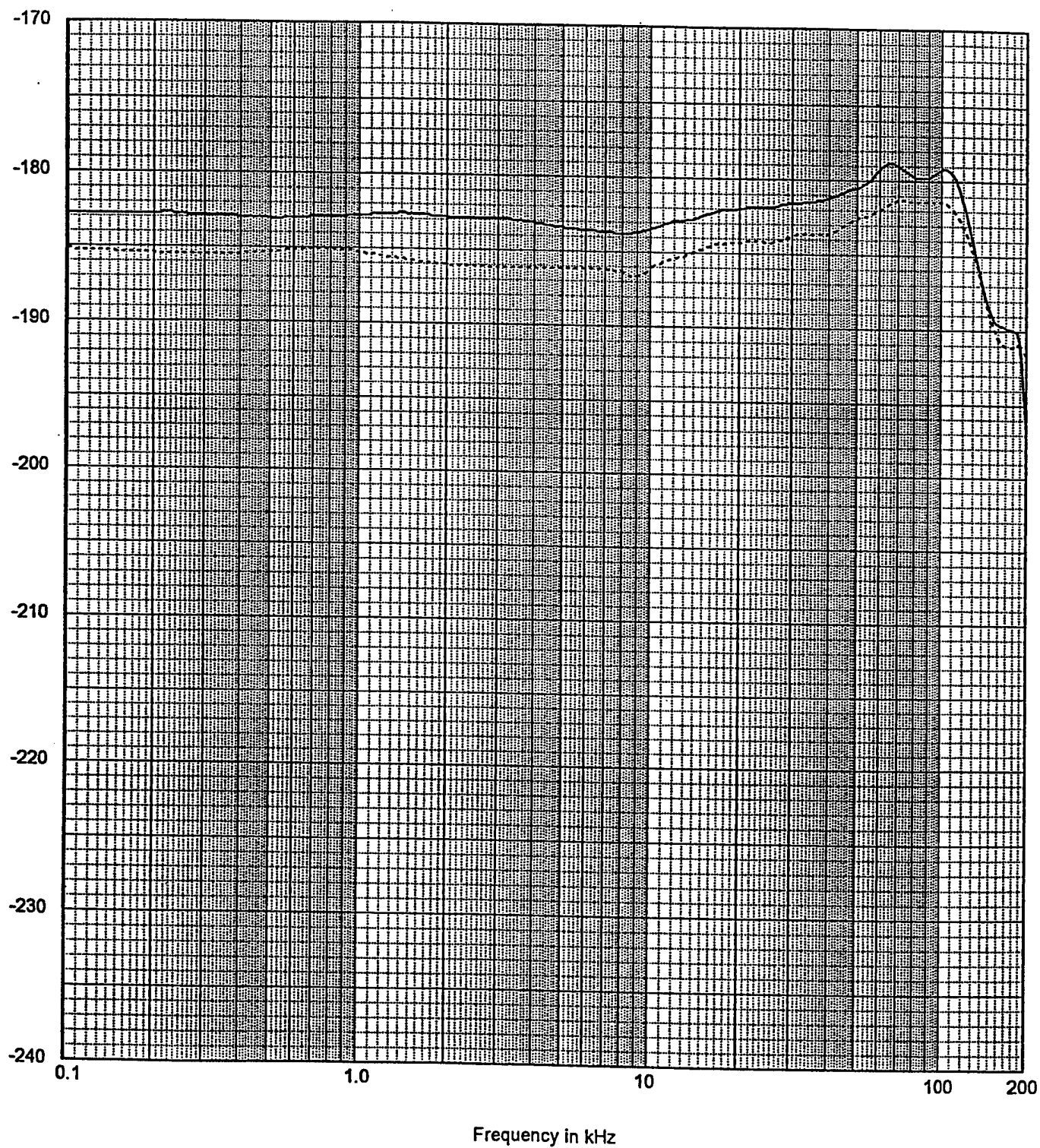


Fig. 10: Free field voltage sensitivity of the copper panel: pre- and post-pressure tests of ATF.

22 °C 14.3 m (140 kPa)

— Pre ATF measurements

----- Post ATF measurements

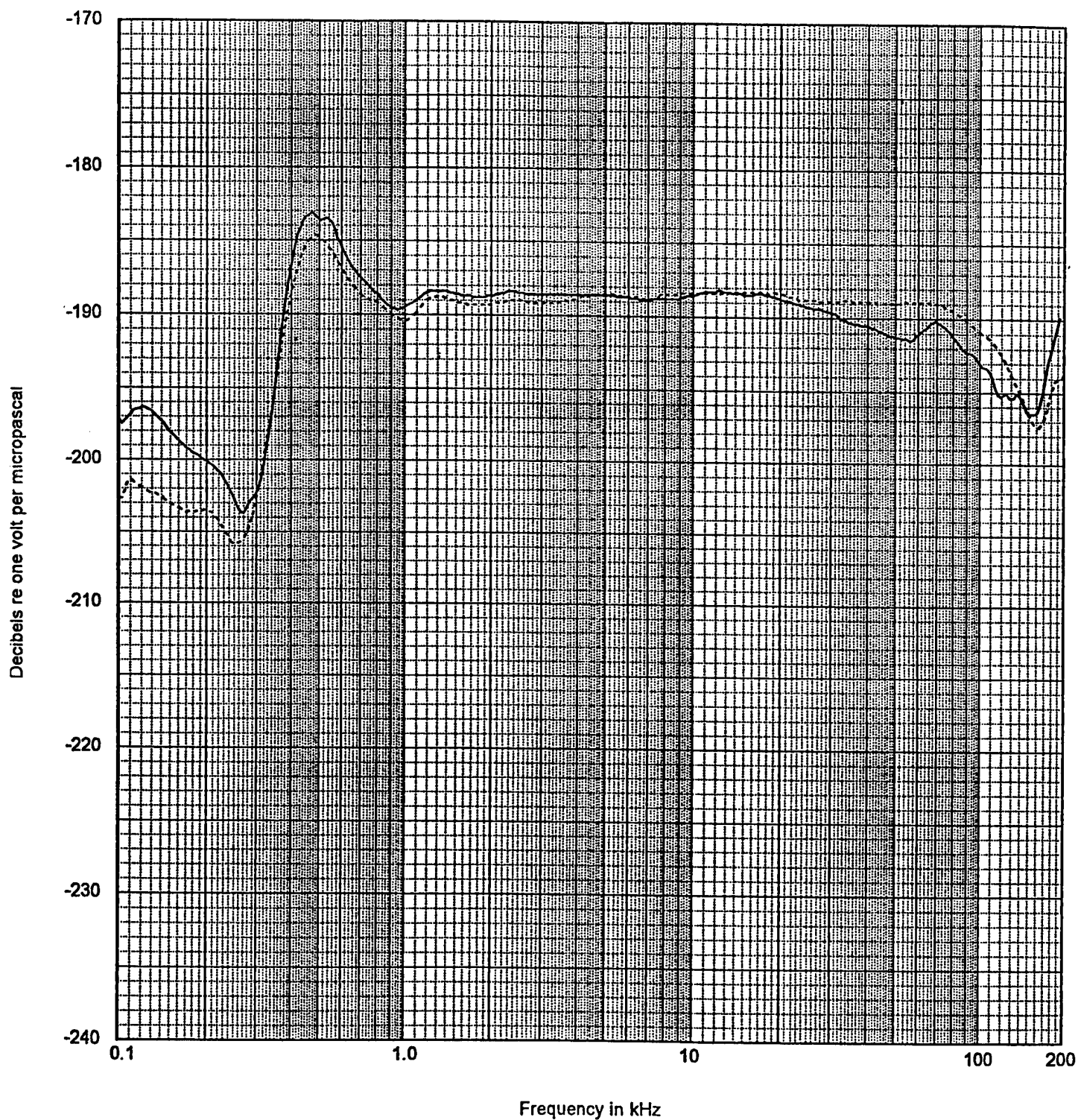


Fig. 11: Free field voltage sensitivity of the silver panel: pre- and post-pressure tests of ATF.



22 °C 14.3 m (140 kPa)

— Post ATF measurements

..... Post ATF measurements, clamped to 3/8 in. steel plate

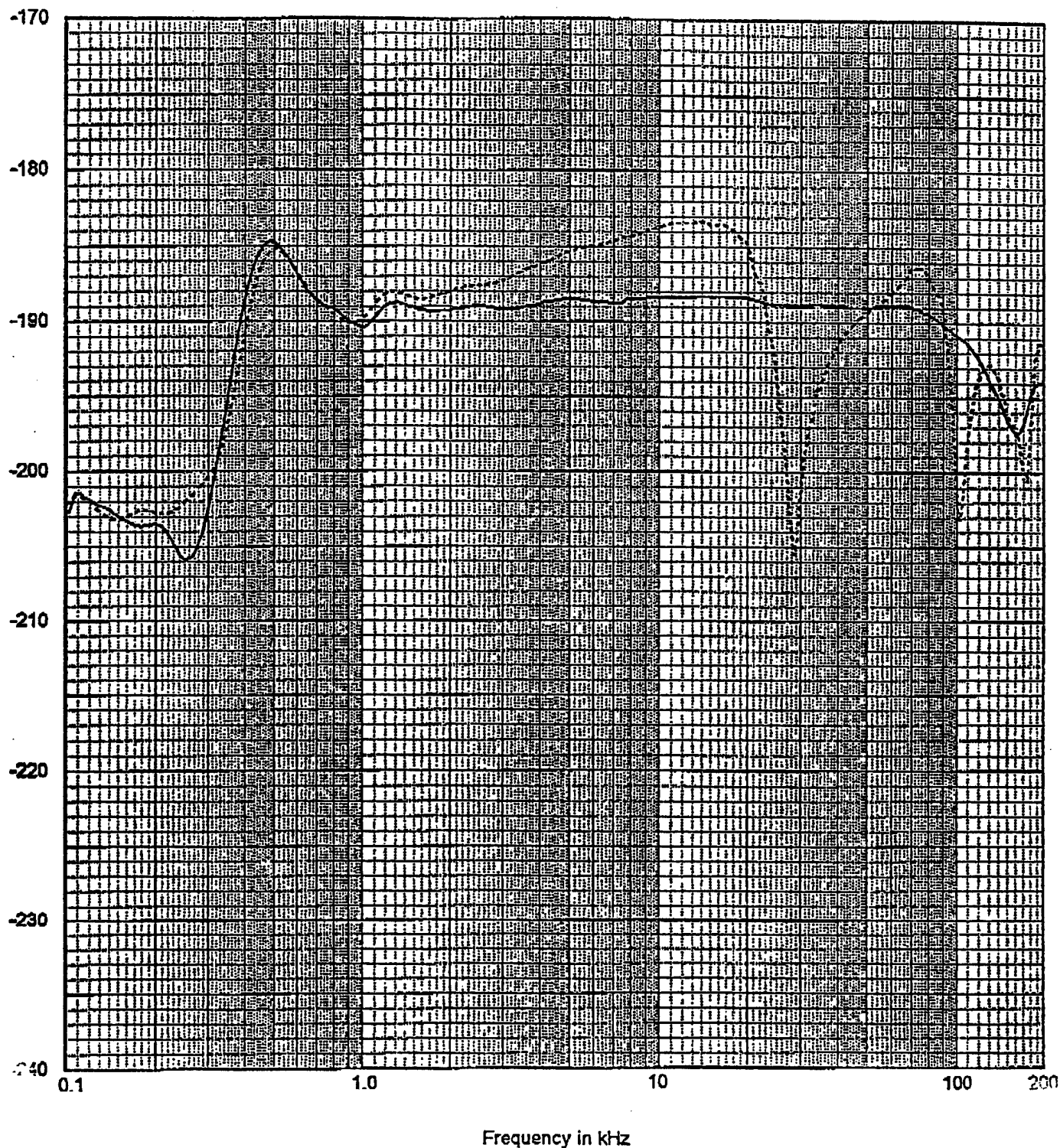


Fig. 12: Free field voltage sensitivity of the silver panel clamped with a 3/8-inch steel plate measured at LeeFac open water after ATF pressure tests.



22 °C 14.3 m (140 kPa)

— Pre ATF measurements

----- Post ATF measurements

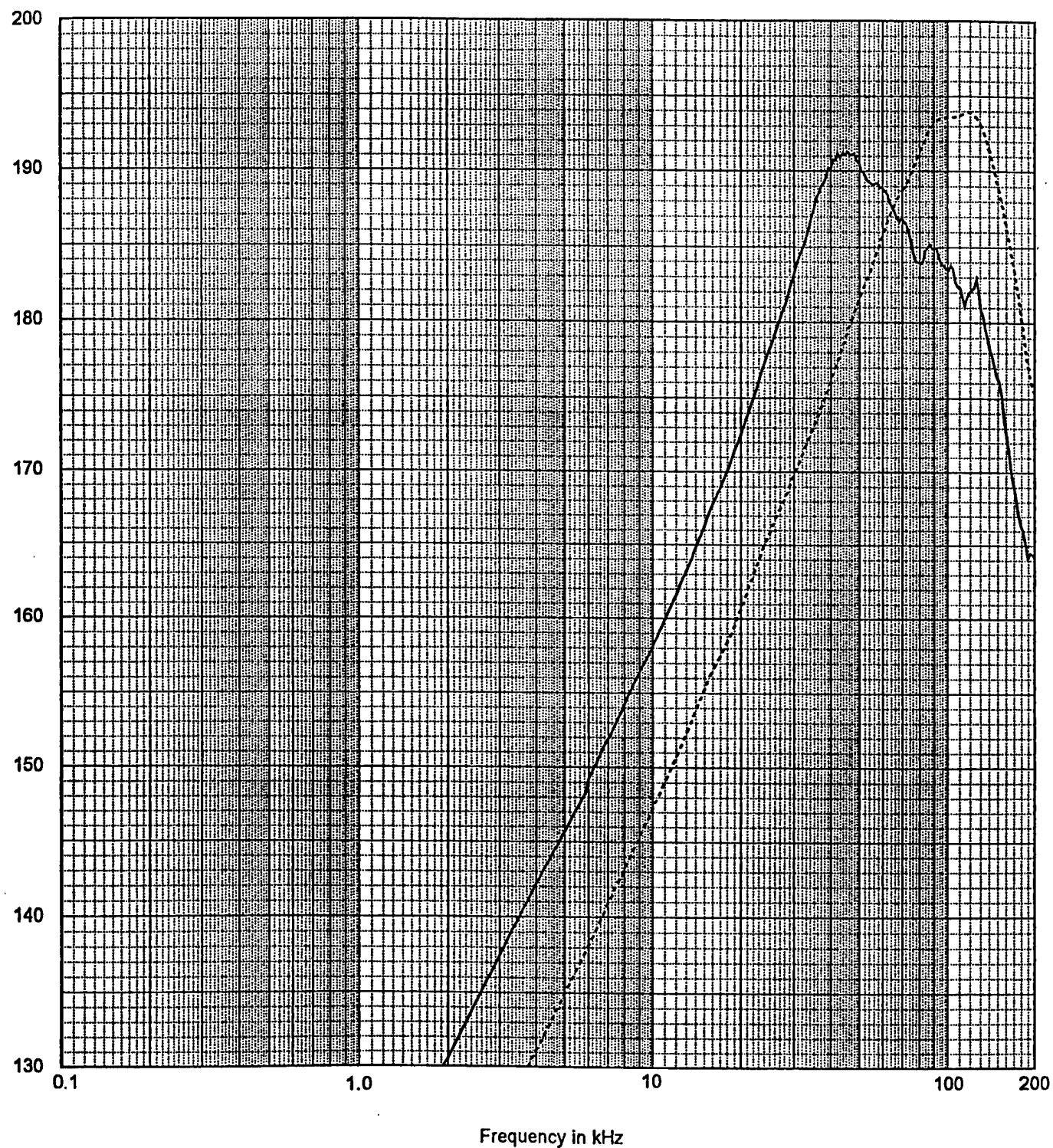


Fig. 13: Open water transmitting voltage response of the copper panel measured at Lee Fac.

22 °C 14.3 m (140 kPa)  
— Pre ATF measurements  
- - - Post ATF measurements

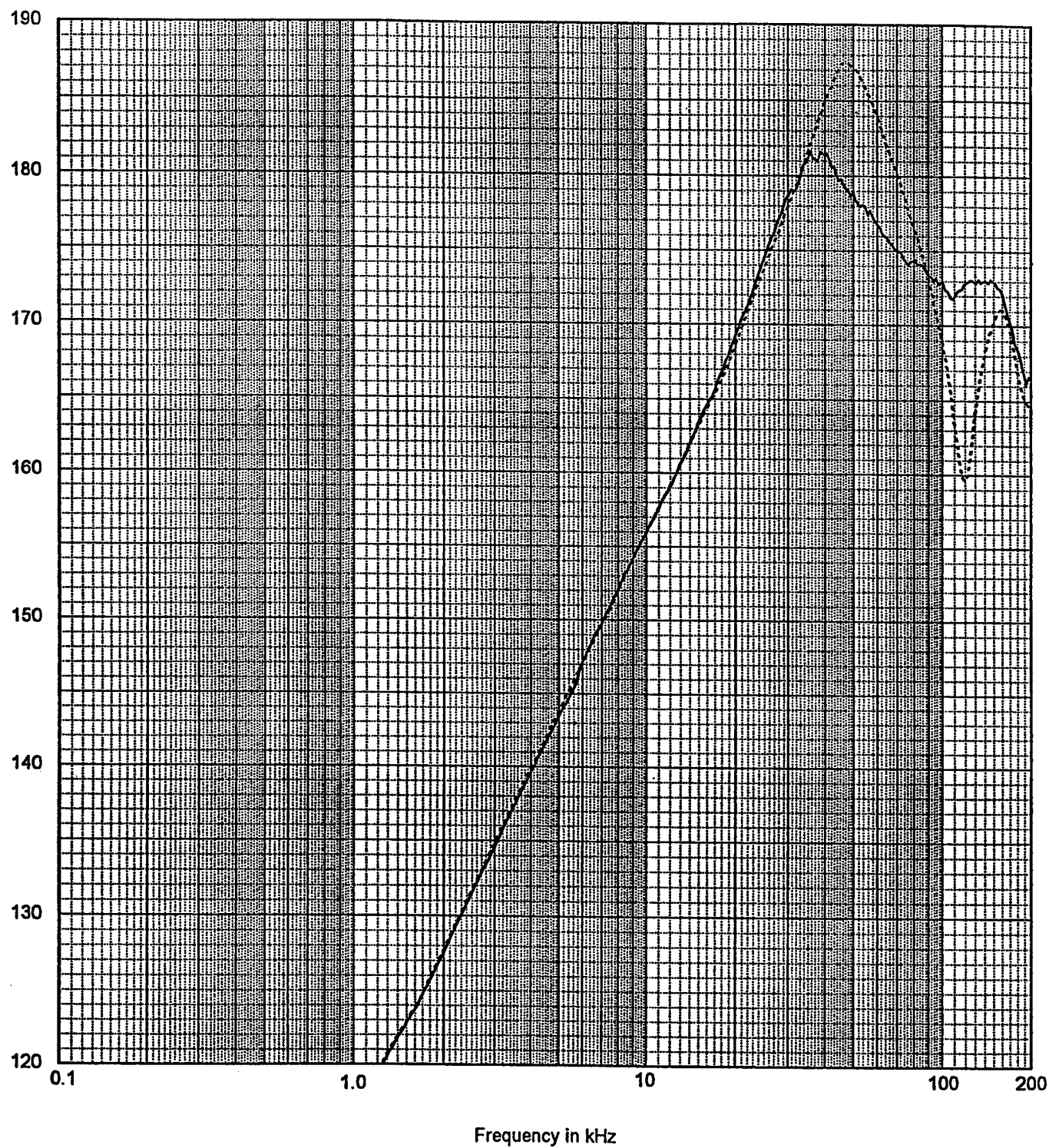


Fig. 14: Open water transmitting voltage response of the silver panel measured at Lee Fac.

Water Temp: 22° C

———— 16 kPa ( 1.6 m )  
----- 689 kPa ( 70.3 m )  
..... 3450 kPa ( 352.0 m )  
----- 6890 kPa ( 703.0 m )  
----- 16 kPa ( 1.6 m ) After Pressure

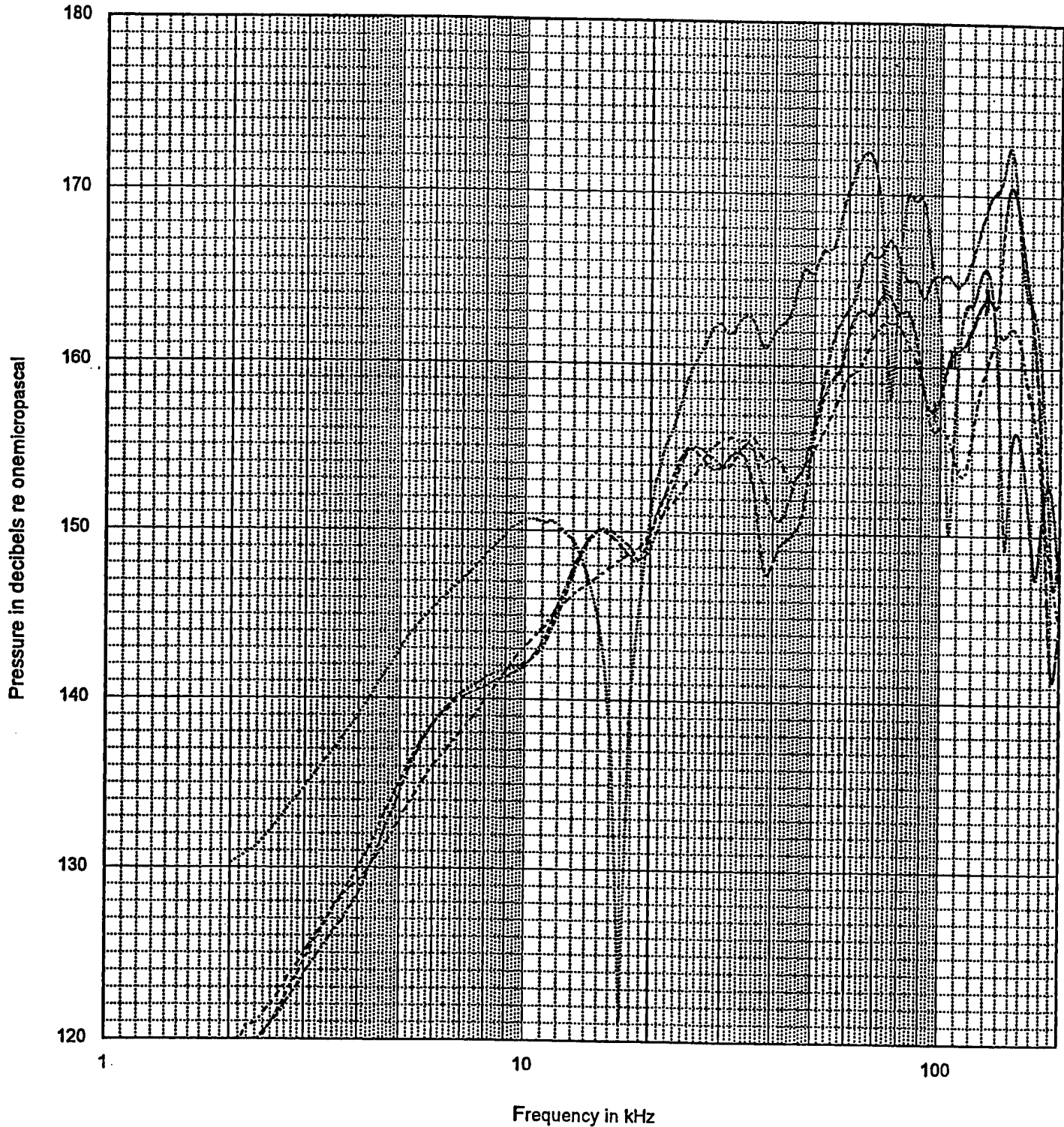


Fig. 15: Transmitting voltage response of the copper panel as a function of pressure at 22-deg C.

Water Temp: 3° C

—— 16 kPa ( 1.6 m )  
----- 689 kPa ( 70.3 m )  
----- 3450 kPa ( 352.0 m )  
----- 6890 kPa ( 703.0 m )  
----- 16 kPa ( 1.6 m ) After Pressure

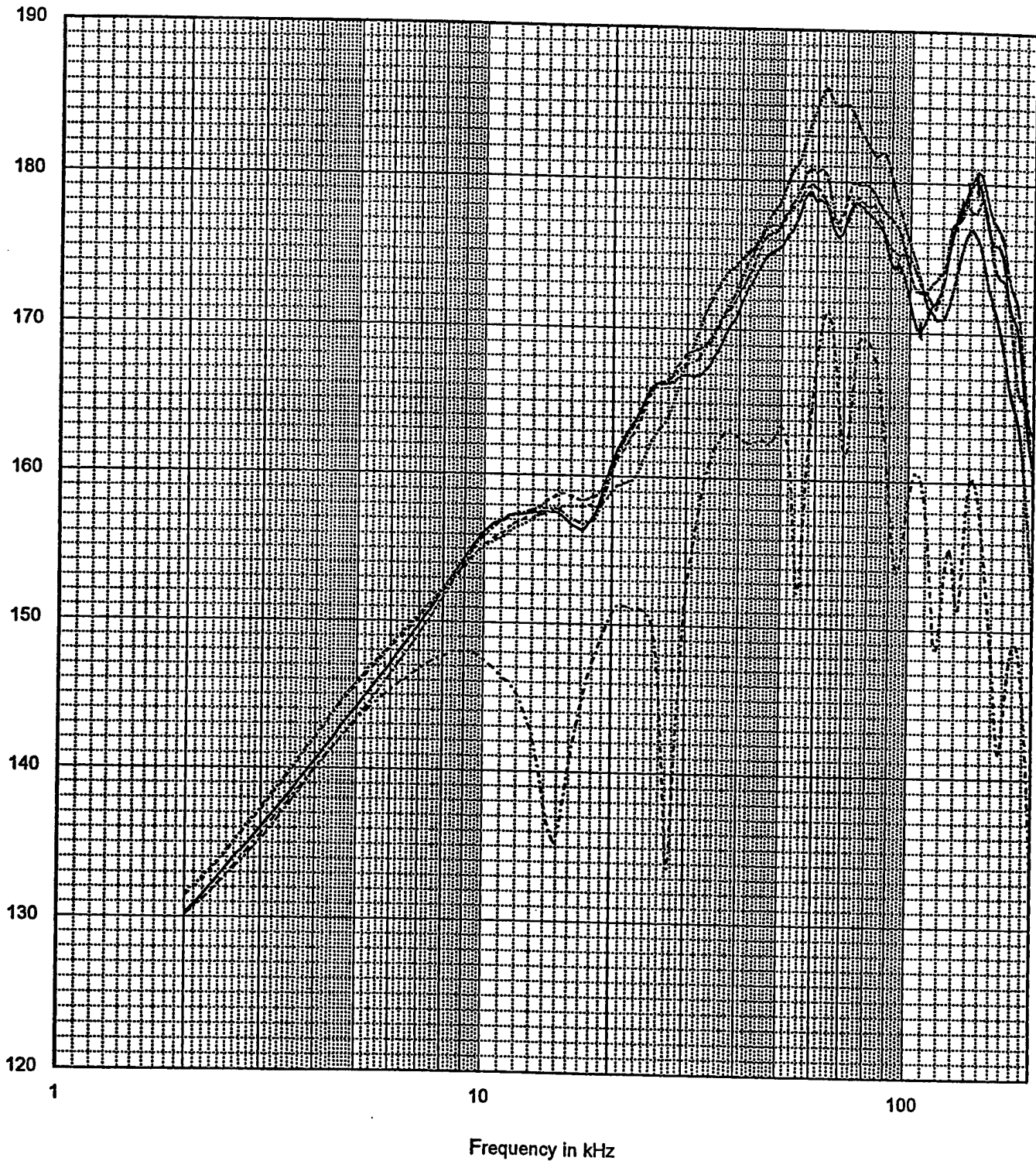


Fig. 16: Transmitting voltage response of the copper panel as a function of pressure at 3-deg C.



Water Temp: 22° C

—— 16 kPa ( 1.6 m )  
----- 689 kPa ( 70.3 m )  
----- 3450 kPa ( 352.0 m )  
----- 6890 kPa ( 703.0 m )  
----- 16 kPa ( 1.6 m ) After Pressure

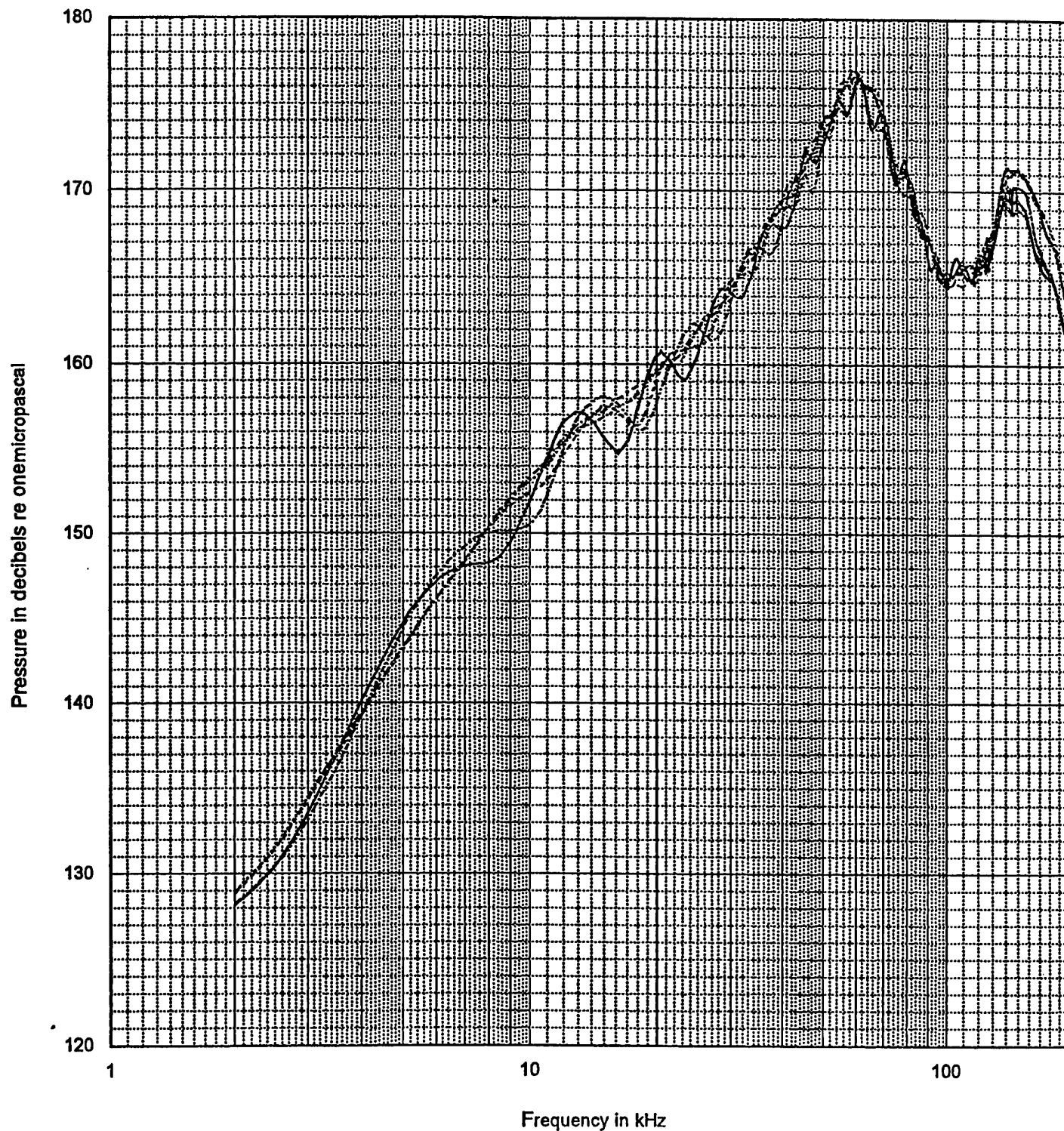


Fig. 17: Transmitting voltage response of the silver panel as a function of pressure at 22-deg C.



Water Temp: 3° C

— 16 kPa ( 1.6 m )  
- - - 689 kPa ( 70.3 m )  
· · · 3450 kPa ( 352.0 m )  
- - - 6890 kPa ( 703.0 m )  
- - - 16 kPa ( 1.6 m ) After Pressure

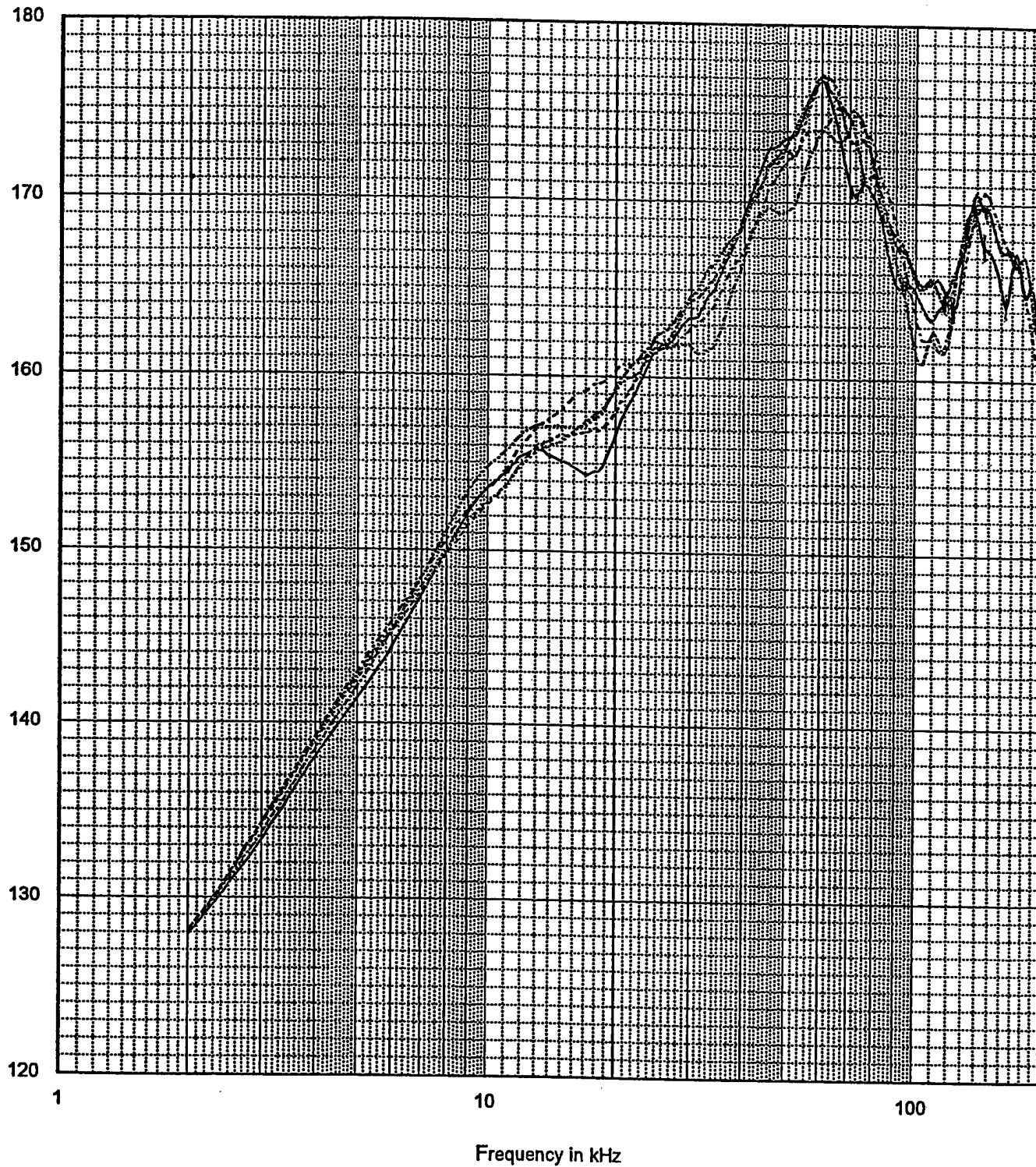


Fig. 18: Transmitting voltage response of the silver panel as a function of pressure at 3-deg C.

Frequency: 10 kHz  
Temperature: 22° C  
Hydrostatic Pressure: 16 kPa ( 1.6 m )

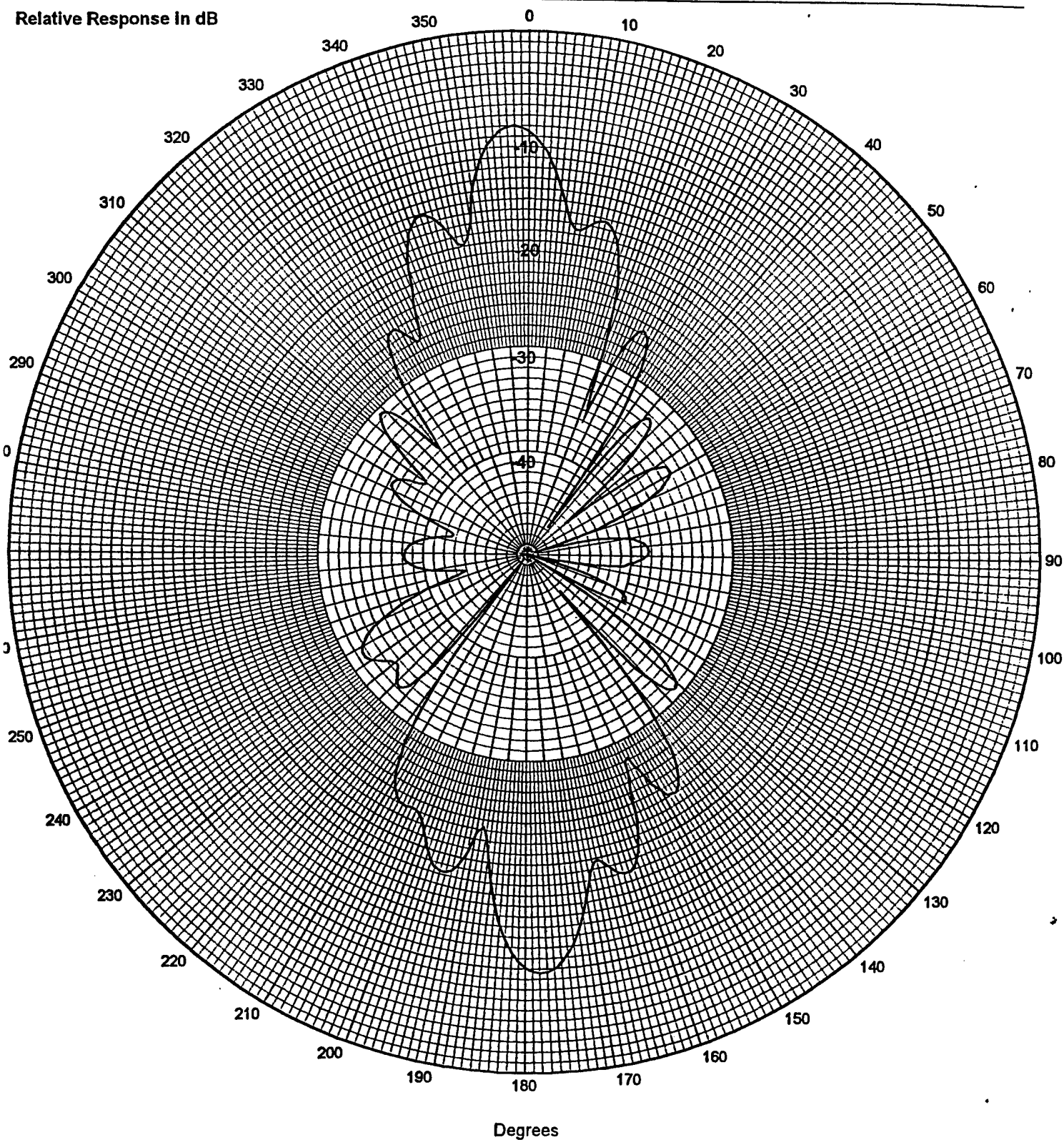


Fig. 19: Directivity panel of the copper panel at 10 kHz and 22-deg C under ambient pressure.

Frequency: 10 kHz  
Temperature: 22° C  
Hydrostatic Pressure: 6890 kPa ( 703.0 m )

Relative Response in dB

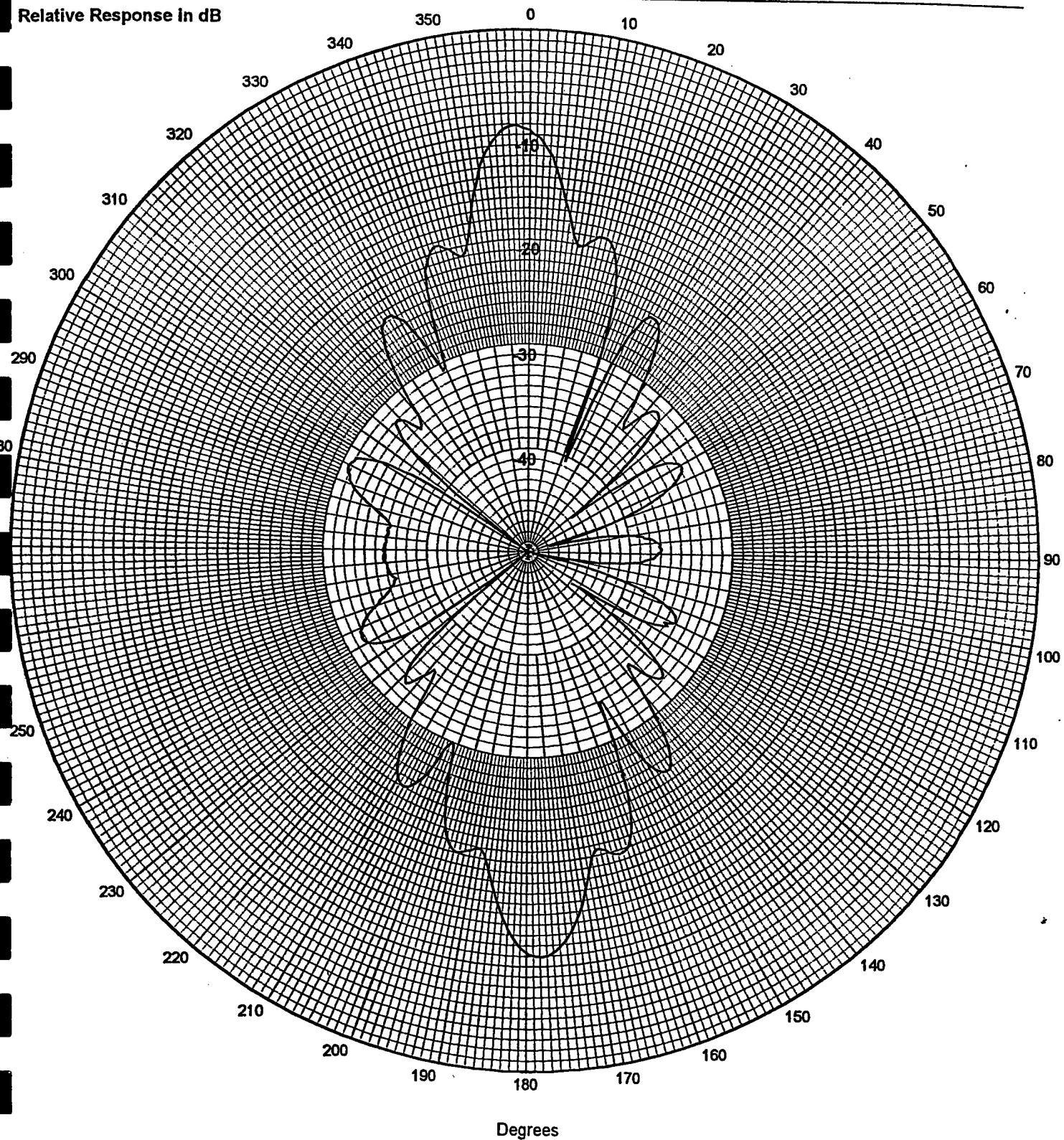


Fig. 20: Directivity panel of the copper panel at 10 kHz and 22-deg C under 1000 psi pressure.

Frequency: 10 kHz  
Temperature: 3° C  
Hydrostatic Pressure: 16 kPa ( 1.6 m )

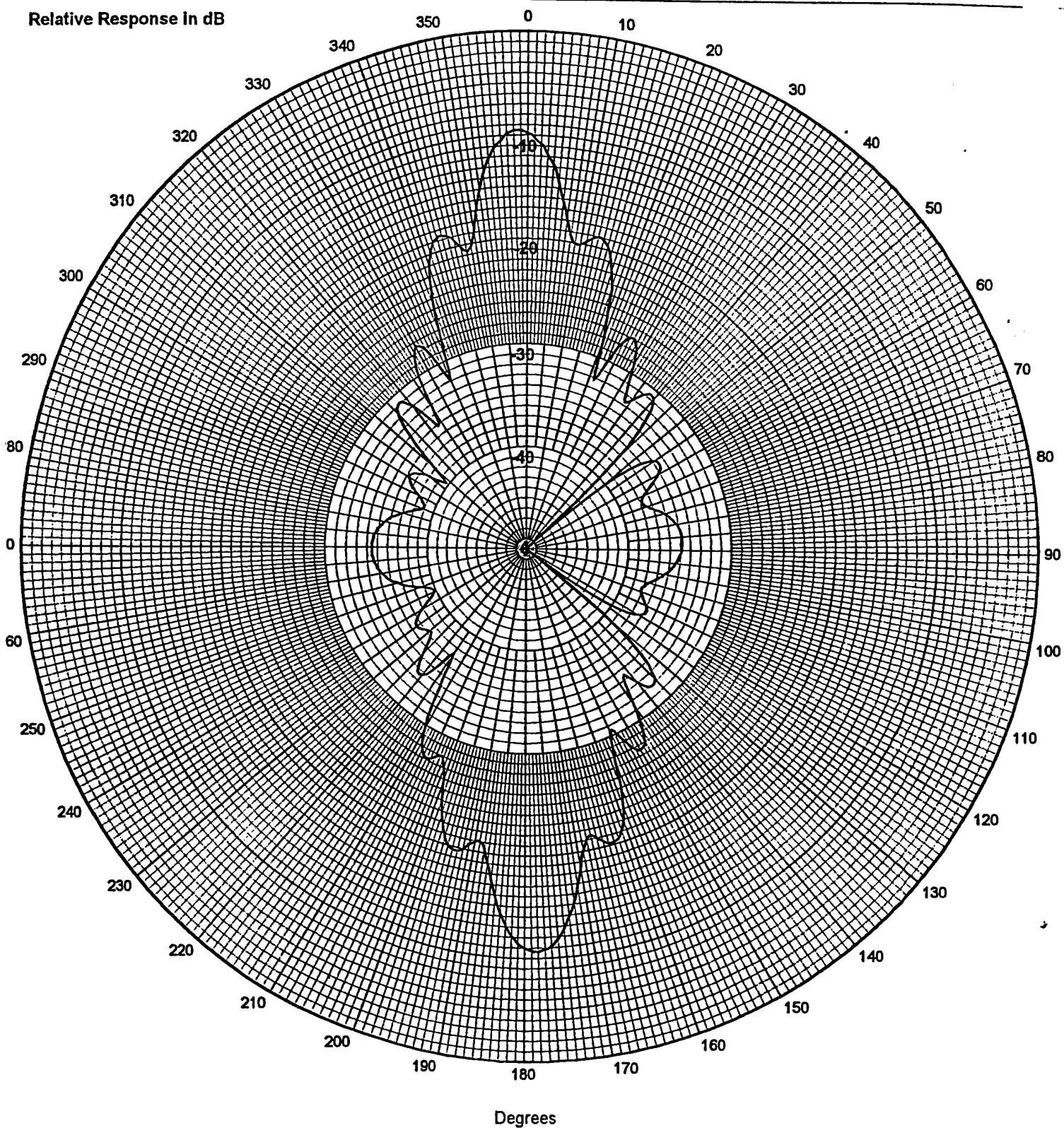


Fig. 21: Directivity panel of the copper panel at 10 kHz and 3-deg C under ambient pressure.



Frequency: 10 kHz  
Temperature: 3° C  
Hydrostatic Pressure: 6890 kPa ( 703.0 m )

Relative Response in dB

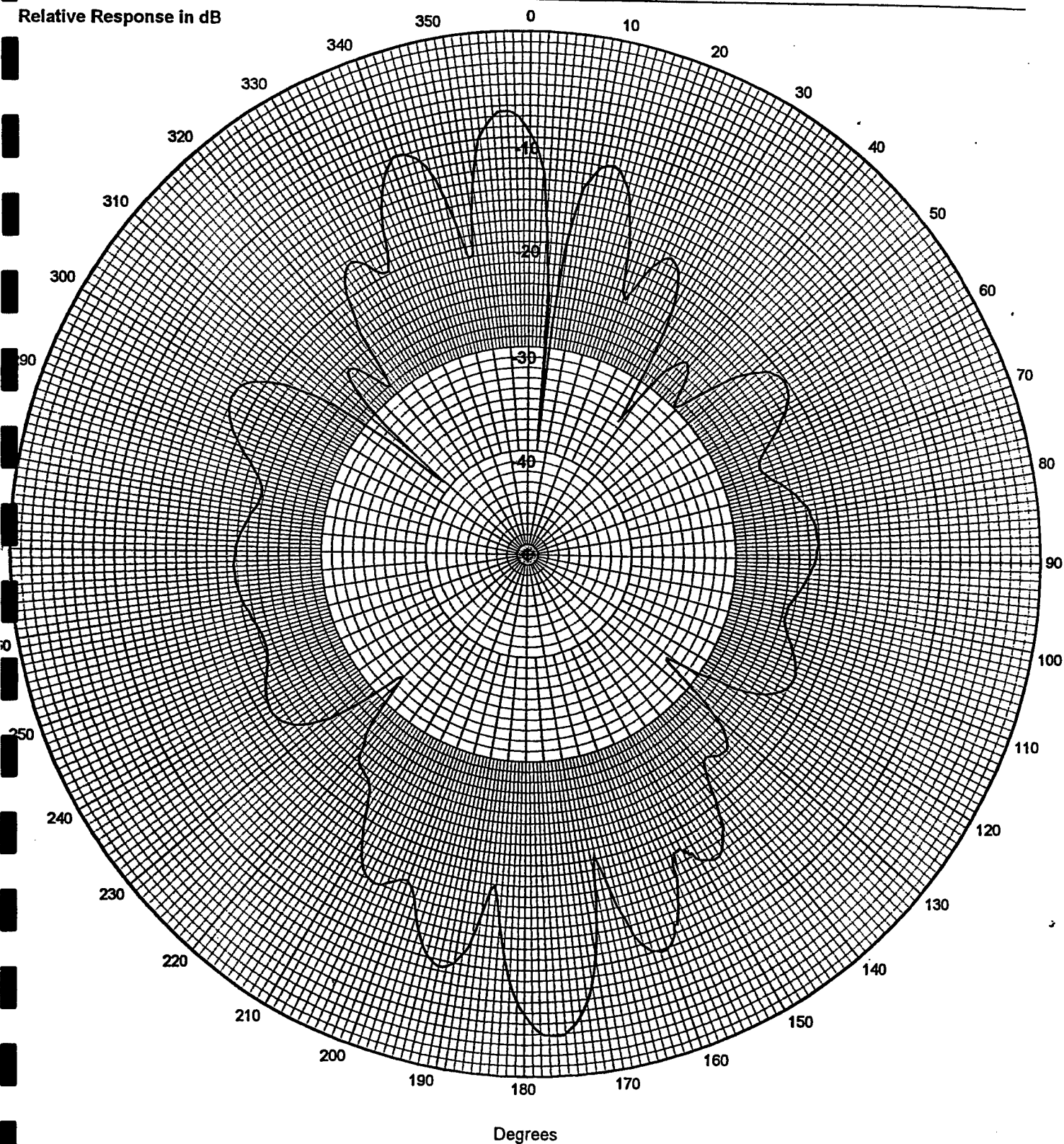


Fig. 22: Directivity panel of the copper panel at 10 kHz and 3-deg C under 1000 psi pressure.



Frequency: 10 kHz  
Temperature: 3° C  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

Relative Response In dB

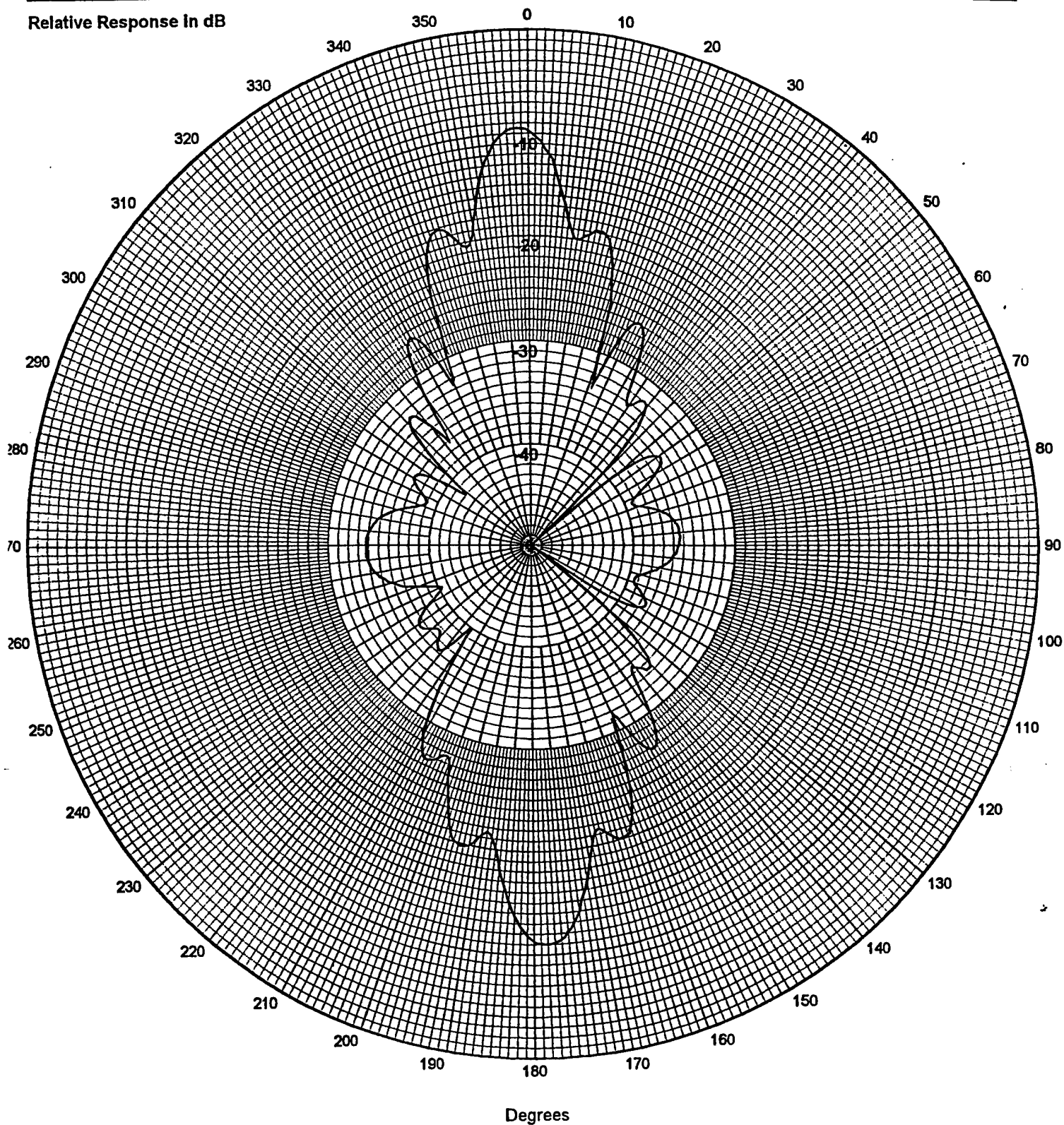


Fig. 23: Directivity panel of the copper panel at 10 kHz and 3-deg back to ambient after pressure test.

Frequency: 10 kHz  
Temperature: 22° C  
Hydrostatic Pressure: 16 kPa ( 1.6 m )

Relative Response in dB

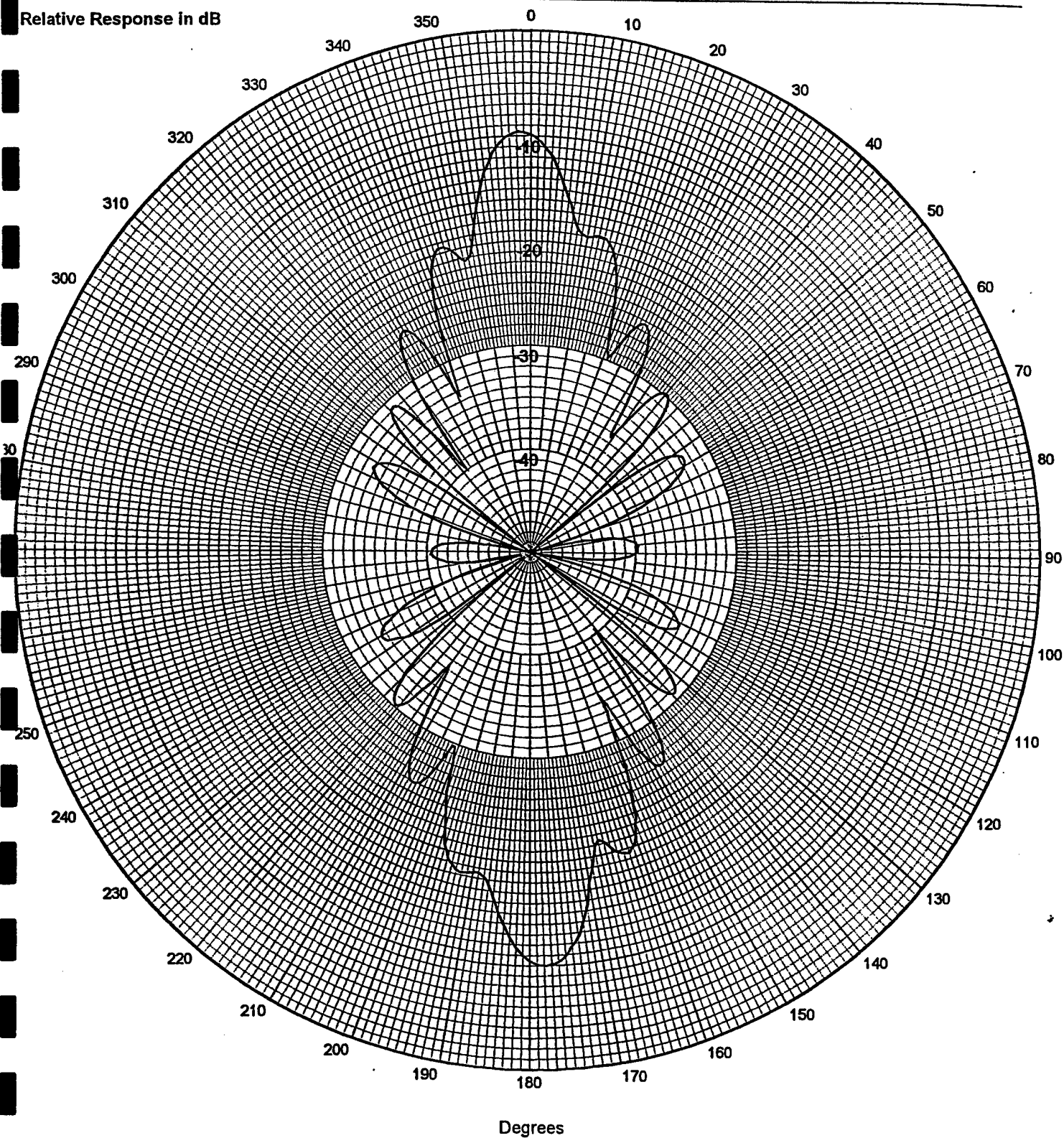


Fig. 24: Directivity panel of the silver panel at 10 kHz and 22-deg C under ambient pressure.

Frequency: 10 kHz  
Temperature: 22° C  
Hydrostatic Pressure: 3450 kPa ( 352.0 m )

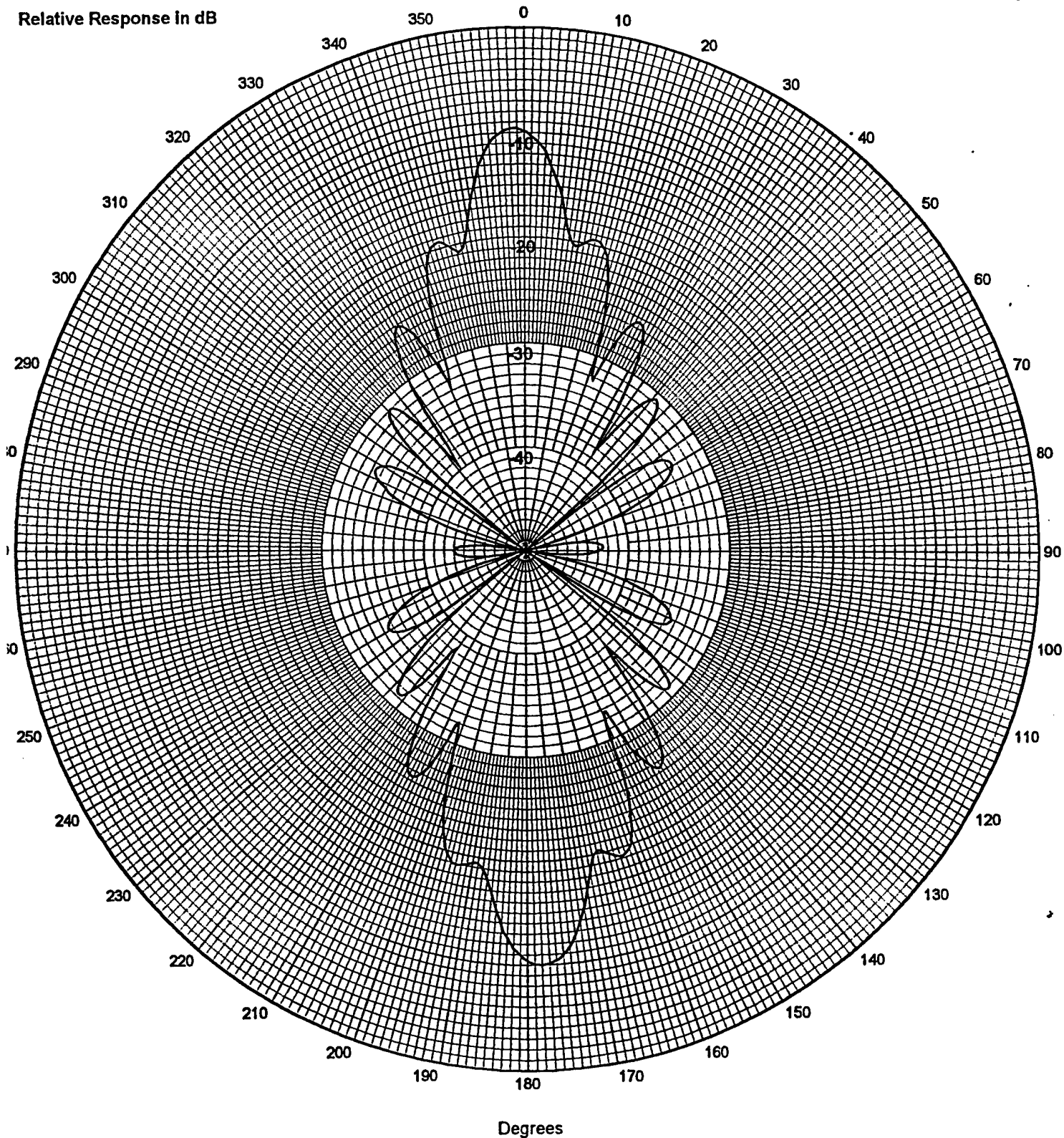


Fig. 25: Directivity panel of the silver panel at 10 kHz and 22-deg C under 500 psi pressure.

Frequency: 10 kHz  
Temperature: 3° C  
Hydrostatic Pressure: 16 kPa ( 1.6 m )

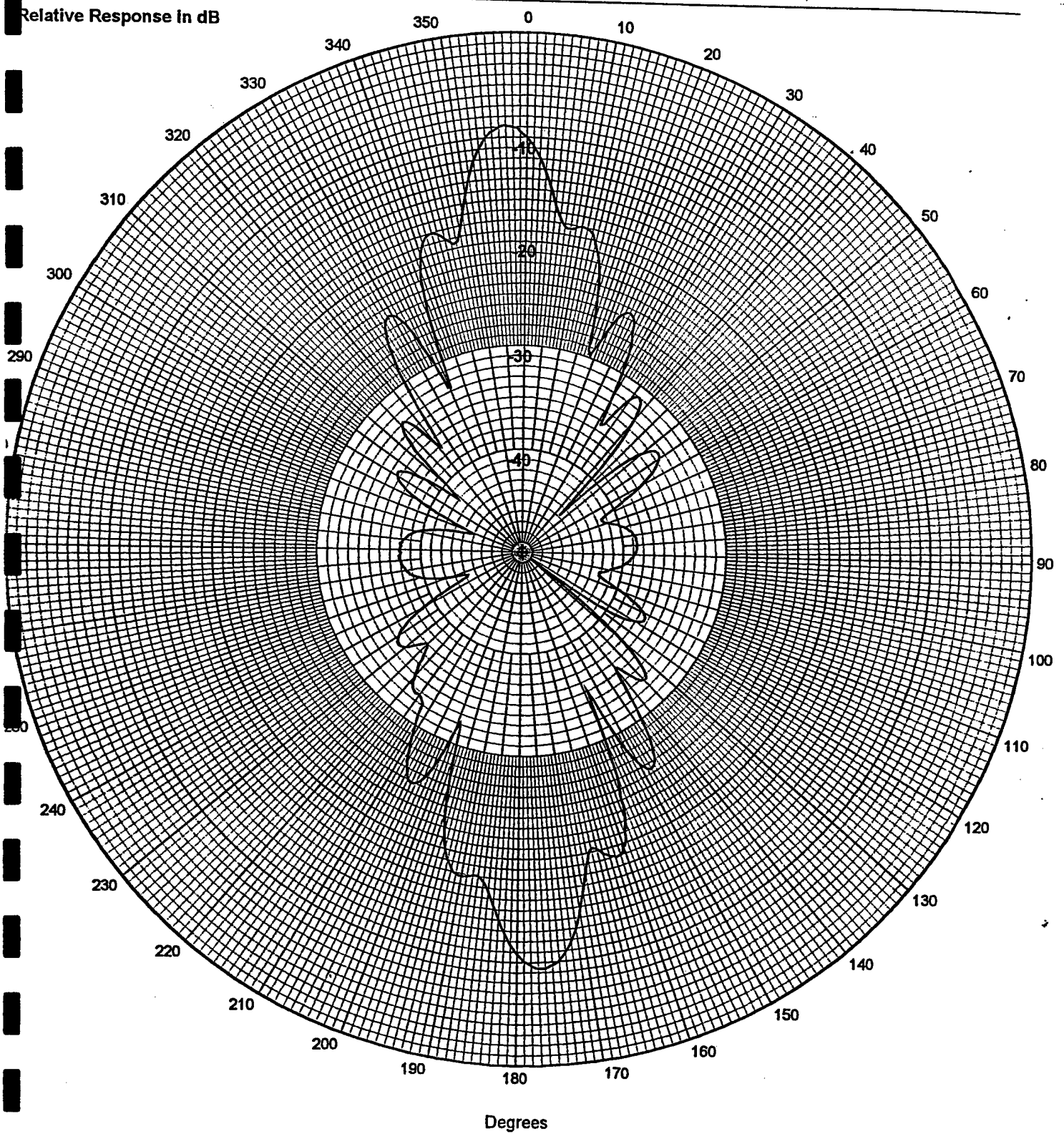


Fig. 26: Directivity panel of the silver panel at 10 kHz and 3-deg C under ambient pressure.



Frequency: 10 kHz  
Temperature: 3° C  
Hydrostatic Pressure: 6890 kPa (.703.0 m )

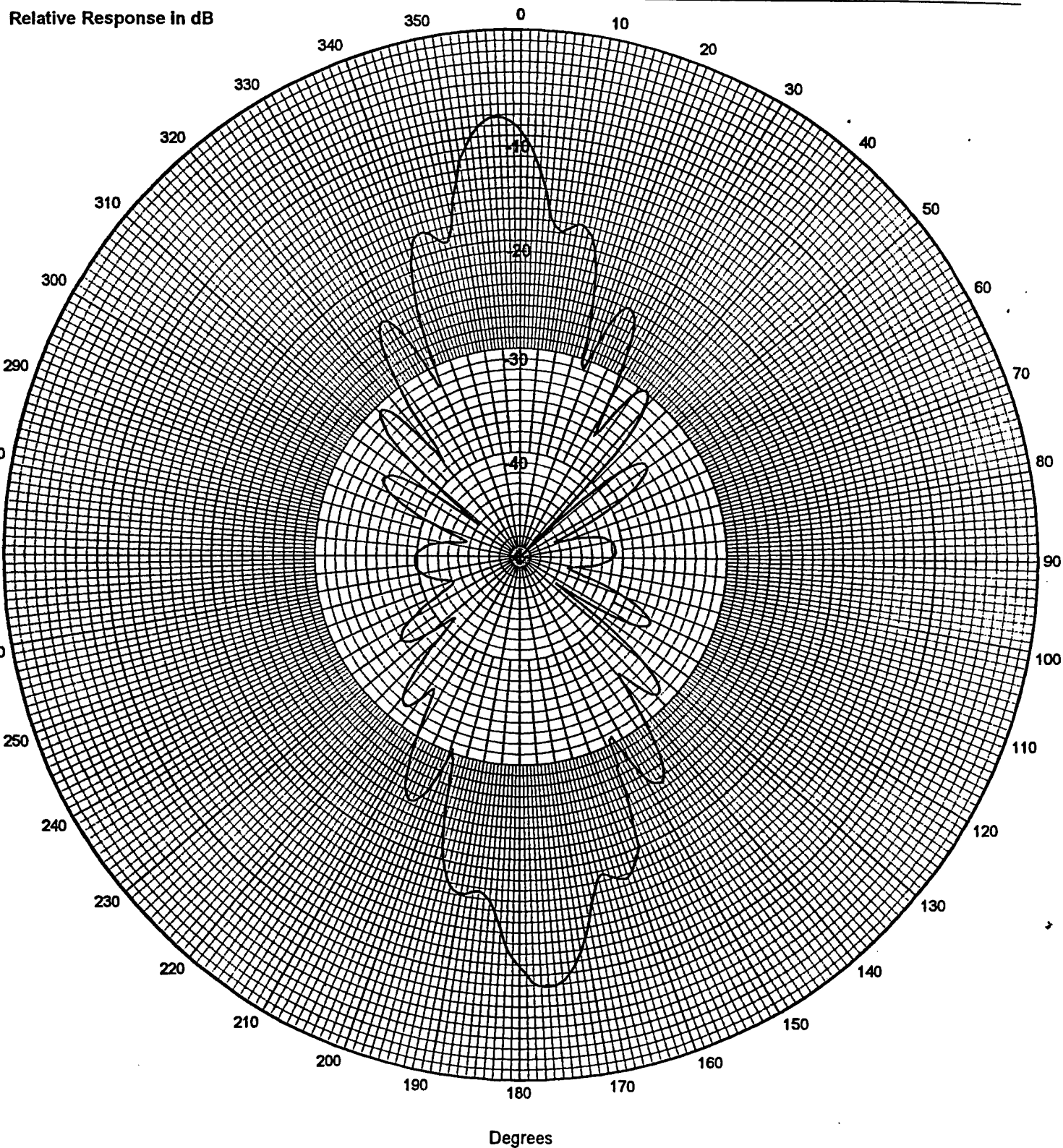


Fig. 27: Directivity panel of the silver panel at 10 kHz and 3-deg C under 1000 psi pressure.

Frequency: 10 kHz  
Temperature: 3° C  
Hydrostatic Pressure: 16 kPa ( 1.6 m ) After Pressure

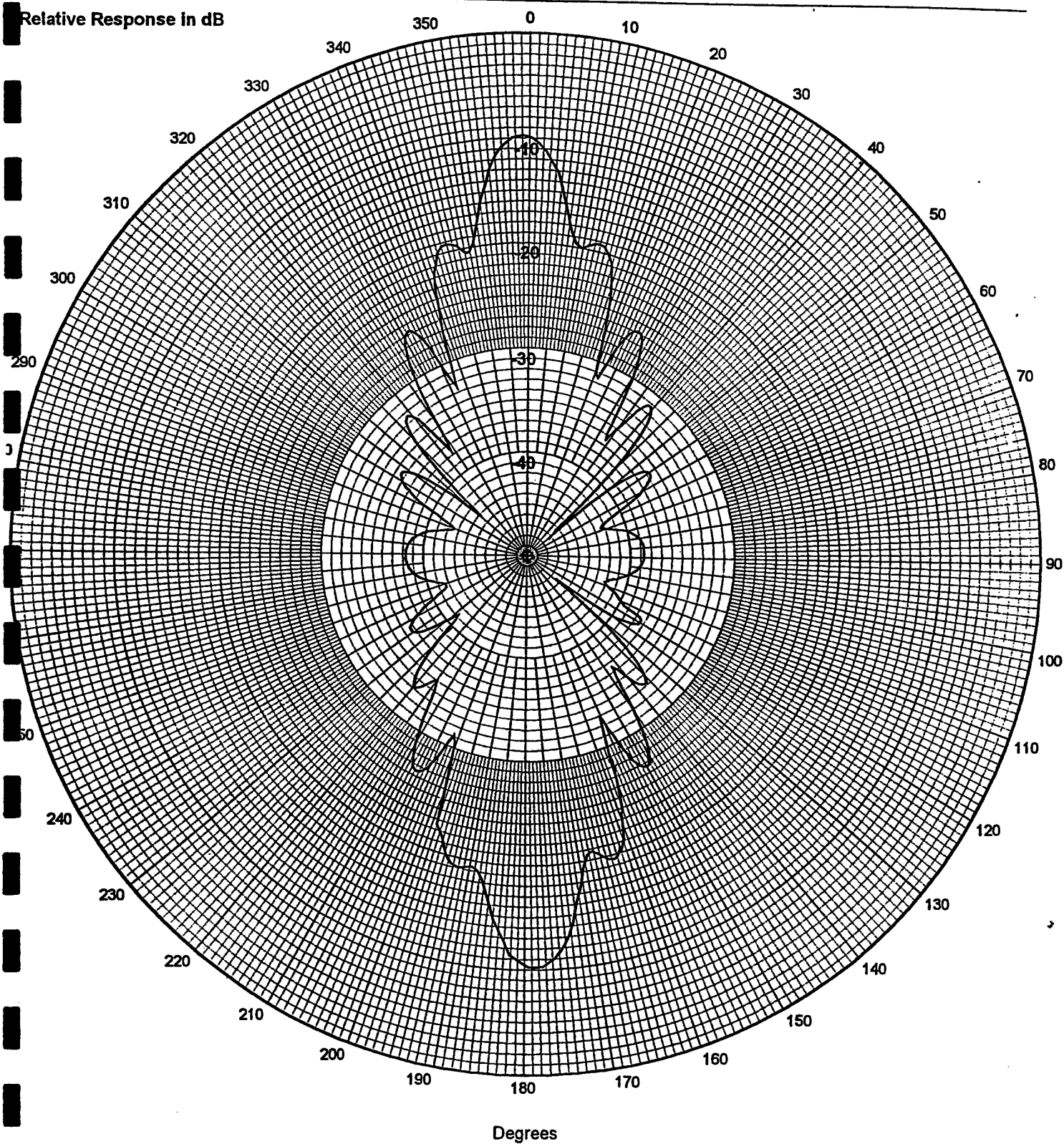


Fig. 28: Directivity panel of the silver panel at 10 kHz and 3-deg back to ambient after pressure test.

10 kHz  
22° C 14.3 m (140 kPa)

Relative Response in dB

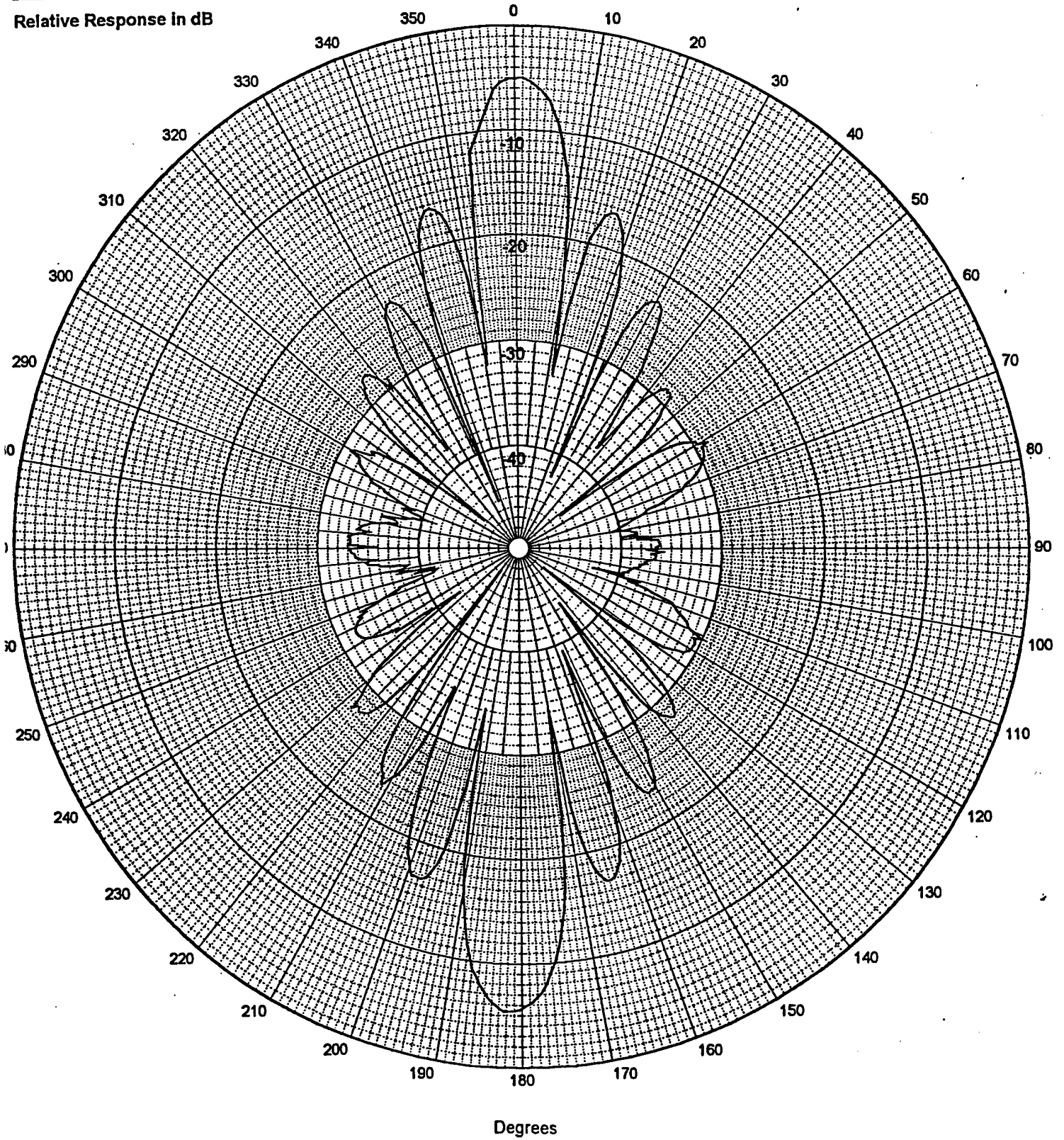


Fig. 29: Directivity pattern of the copper panel at 10 kHz measured at LeeFac: Pre-ATF.

XY Plane  
10 kHz  
22° C 14.3 m (140 kPa)

Relative Response in dB

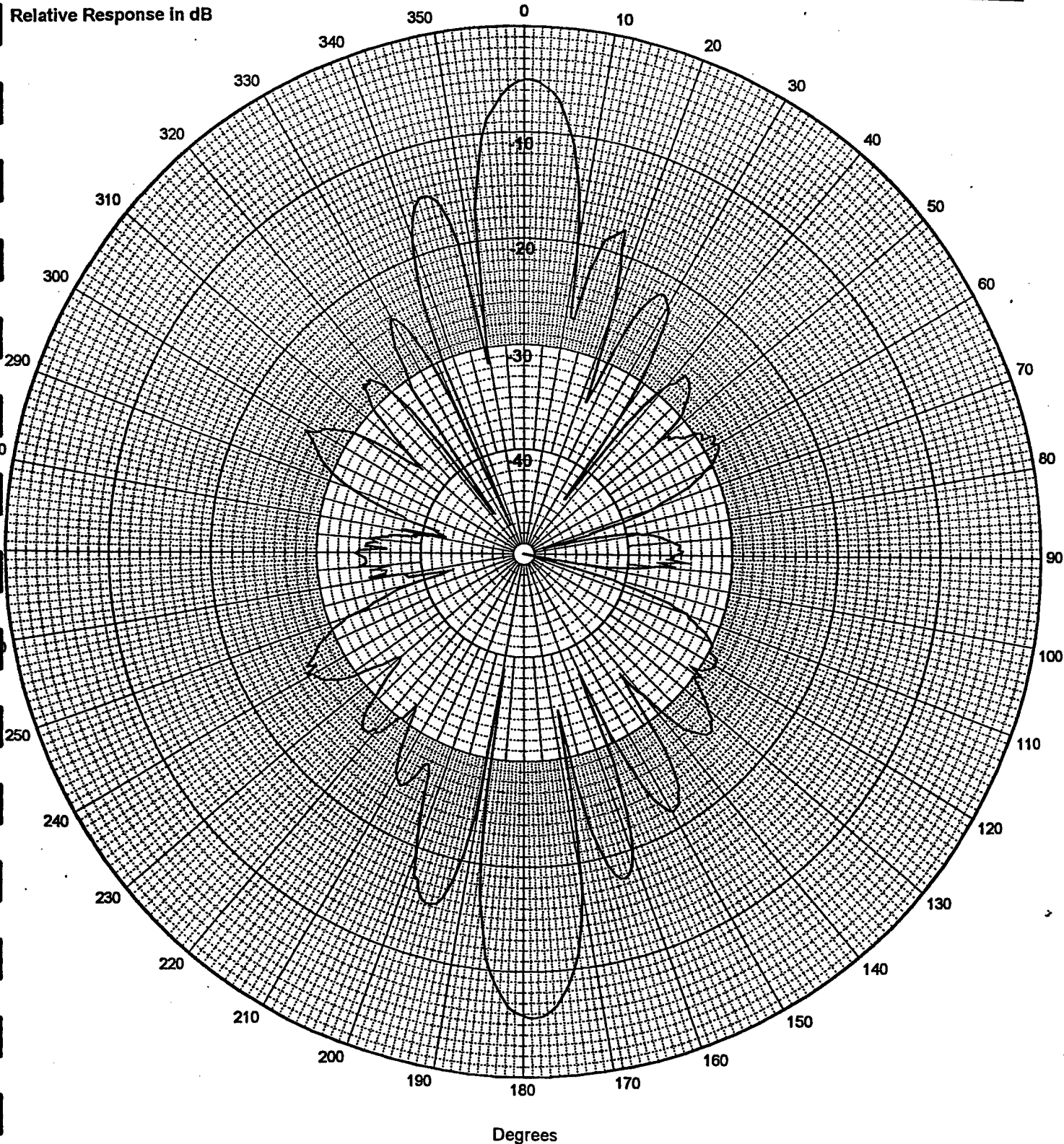


Fig. 30: Directivity pattern of the copper panel at 10 kHz measured at LeeFac: Post-ATF.



XY Plane  
10 kHz  
22° C 14.3 m (140 kPa)

Relative Response in dB

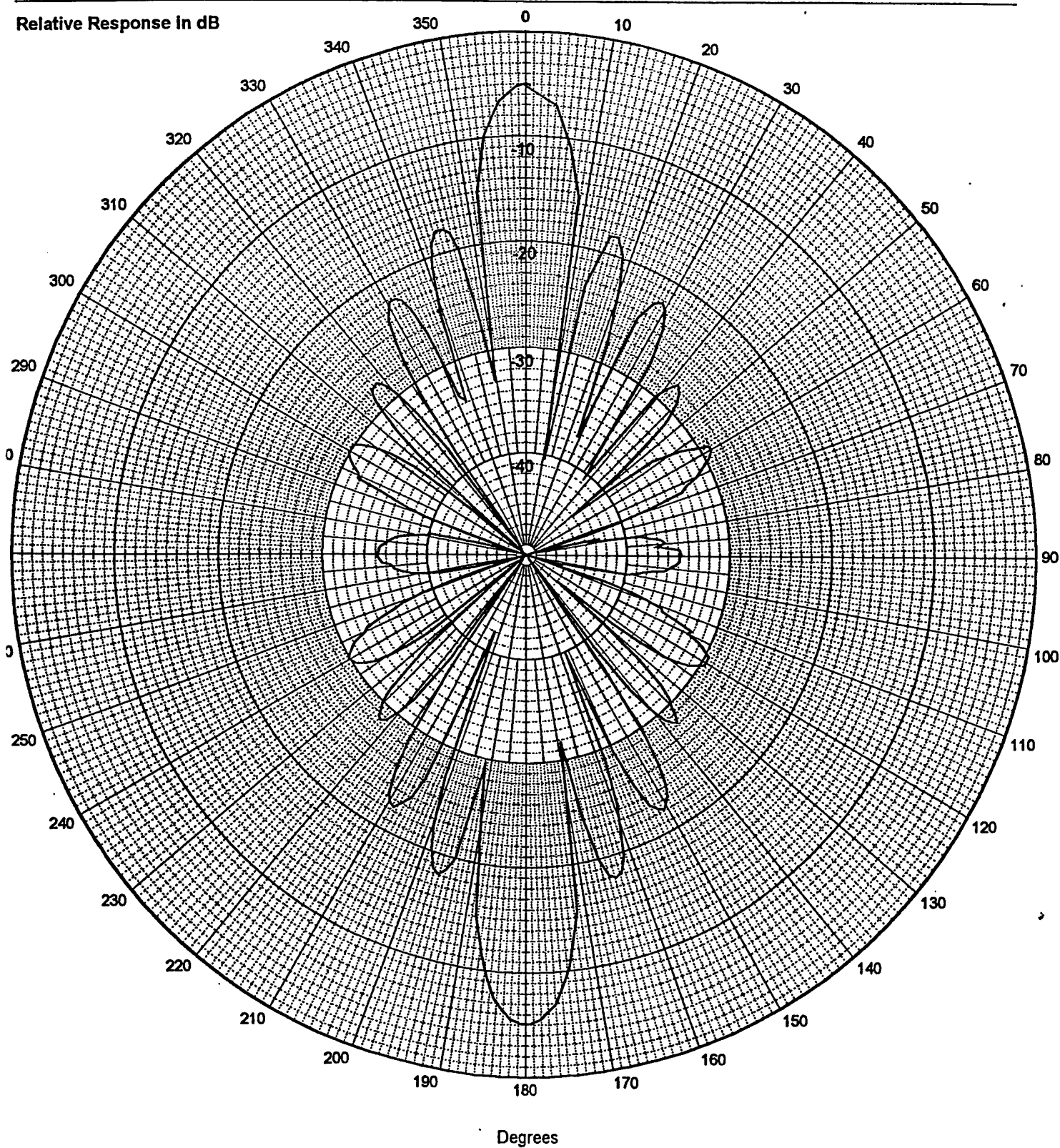


Fig. 31: Directivity pattern of the silver panel at 10 kHz measured at LeeFac: Pre-ATF.

XY Plane  
10 kHz  
22° C 14.3 m (140 kPa)

Relative Response in dB

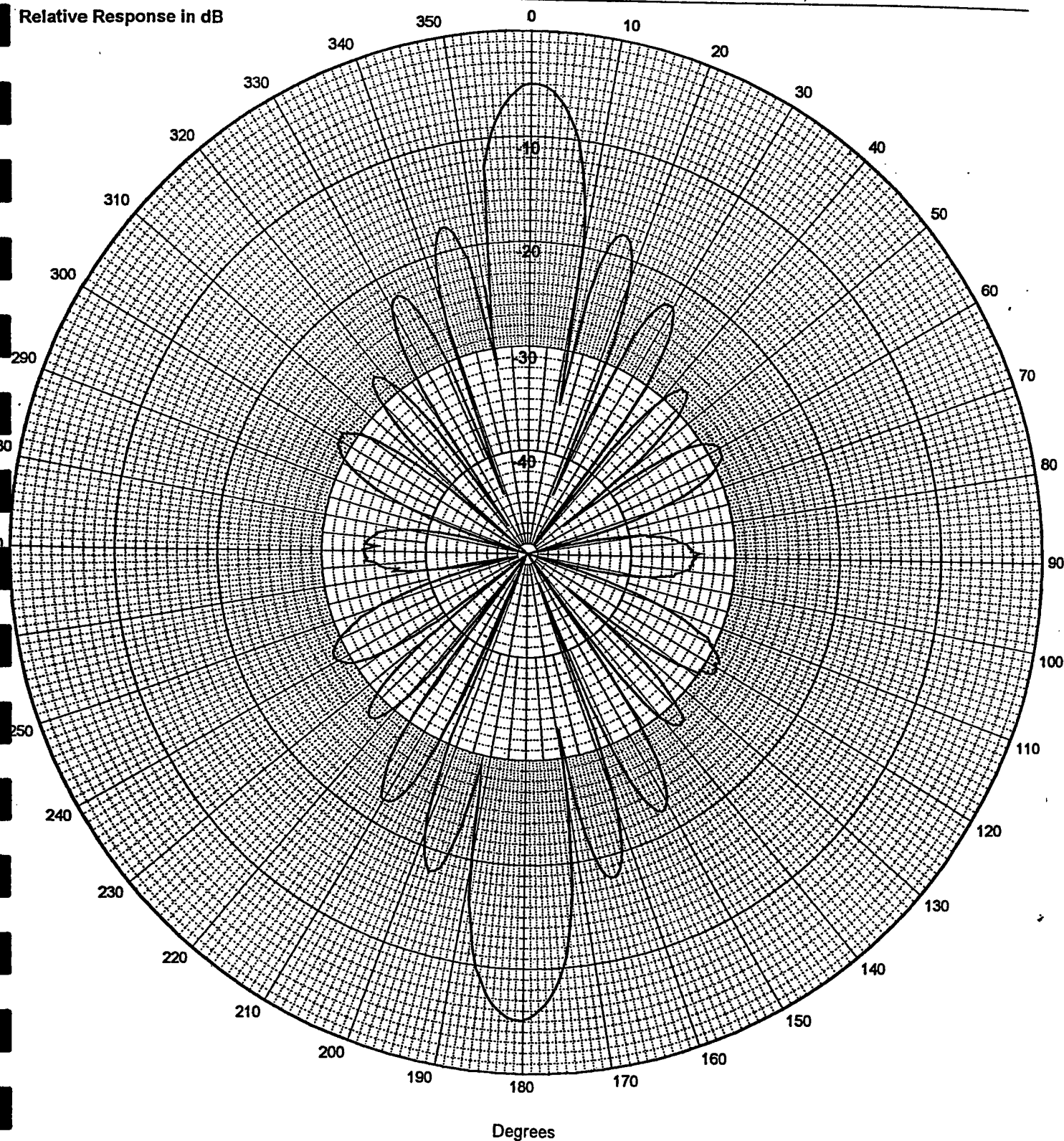


Fig. 32: Directivity pattern of the silver panel at 10 kHz measured at LeeFac: Post-ATF.